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Biss et al.

(10) **Patent No.:** **US 7,219,841 B2**
(45) **Date of Patent:** **May 22, 2007**

(54) **DEVICE AND SYSTEM FOR VERIFYING QUALITY OF BAR CODES**

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U.S. Appl. No. 10/664,581, filed Sep. 17, 2003, Biss, et al.

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Primary Examiner—Seung Ho Lee

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(57) **ABSTRACT**

(73) Assignee: **Hand Held Products, Inc.**, Skaneateles Falls, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 99 days.

(21) Appl. No.: **10/982,393**

(22) Filed: **Nov. 5, 2004**

(65) **Prior Publication Data**

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(51) **Int. Cl.**
G06K 7/10 (2006.01)

(52) **U.S. Cl.** **235/462.25**; 235/454; 235/462.08; 235/462.45

(58) **Field of Classification Search** 235/462.25, 235/462.31, 462.11, 462.24, 462.46, 462.12, 235/462.08, 462.45; 382/112

See application file for complete search history.

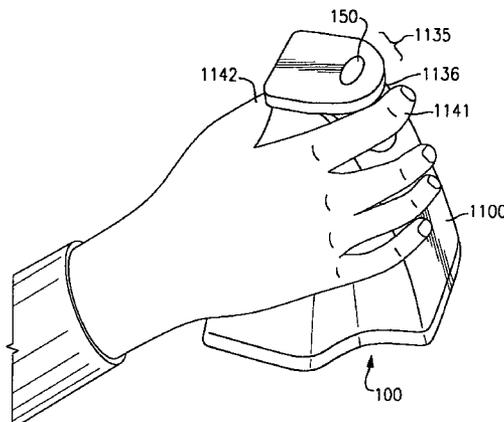
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A device for processing image data relating to bar codes is described. In one embodiment a bar code verification device is provided having an ergonomic form factor characterized by a domed hand held trigger and a viewing window. The verification device may be disposed in a network that includes a host processor system and other bar code reading devices which may include other bar code verification devices. Processing circuitry for processing image signals corresponding to printed bar codes may be partially disposed within the hand held verification device and partially disposed within a host processor system spaced apart from and associated with the hand held verification device. The hand held verification device may be in wireless communication with the host processor system to which it is associated. The bar code verification system may include signal enhancement modules which interpolate constructed pixel values from actual pixel values and which correct for signal degradation resulting from high frequency spatial sampling.

34 Claims, 25 Drawing Sheets



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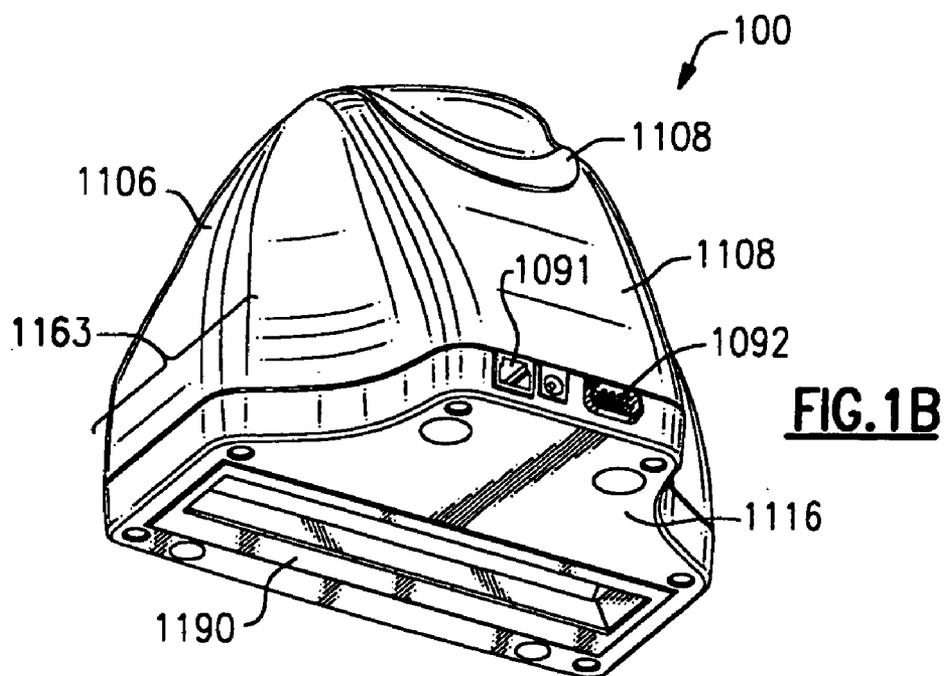
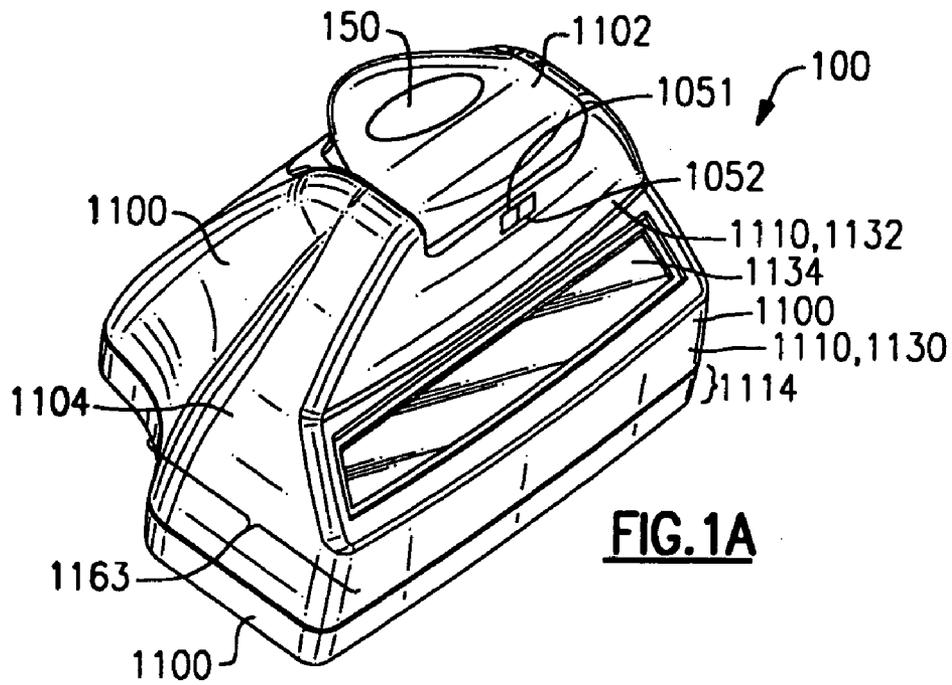
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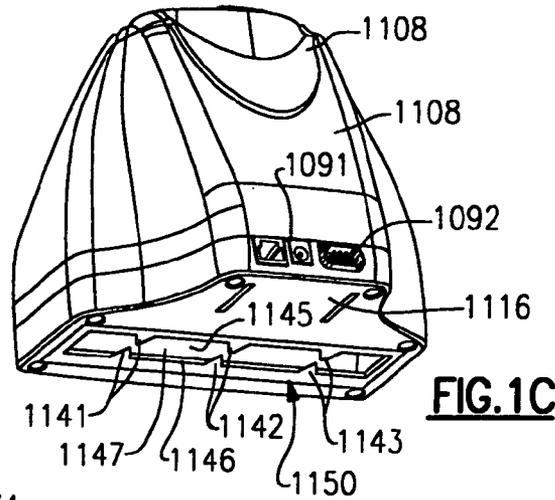


FIG. 1C

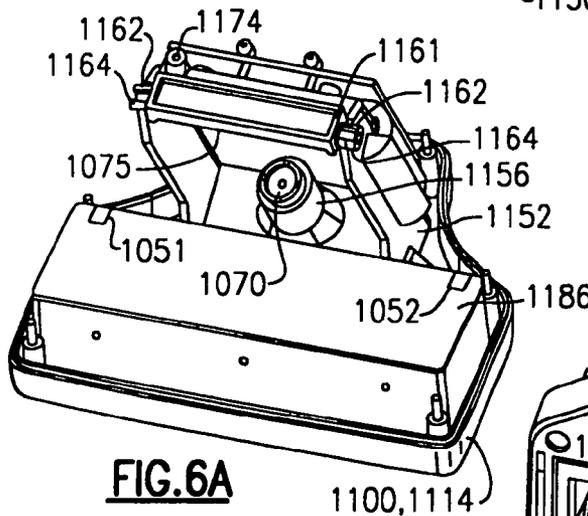


FIG. 6A

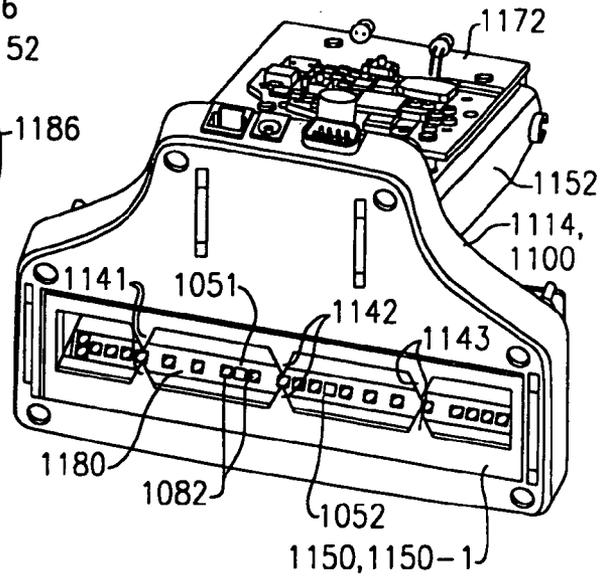


FIG. 6B

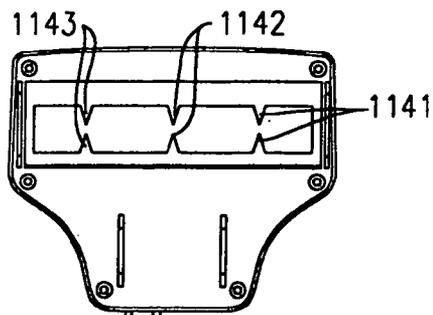


FIG. 6C

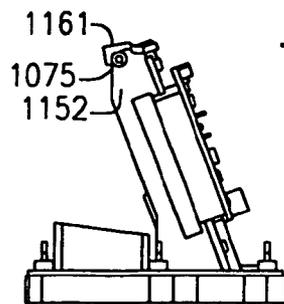
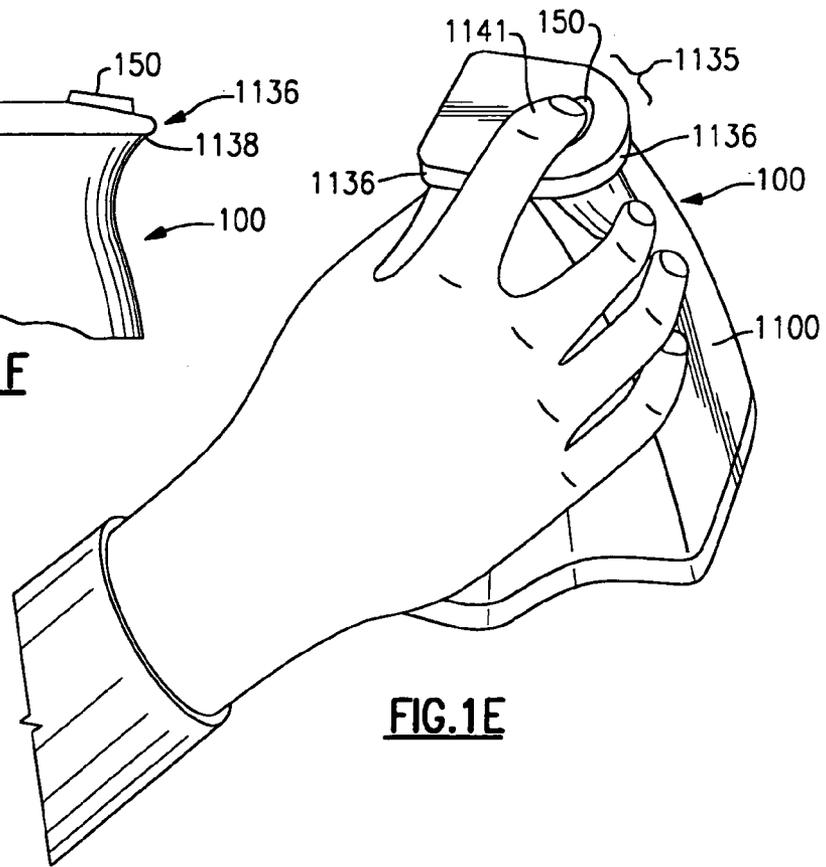
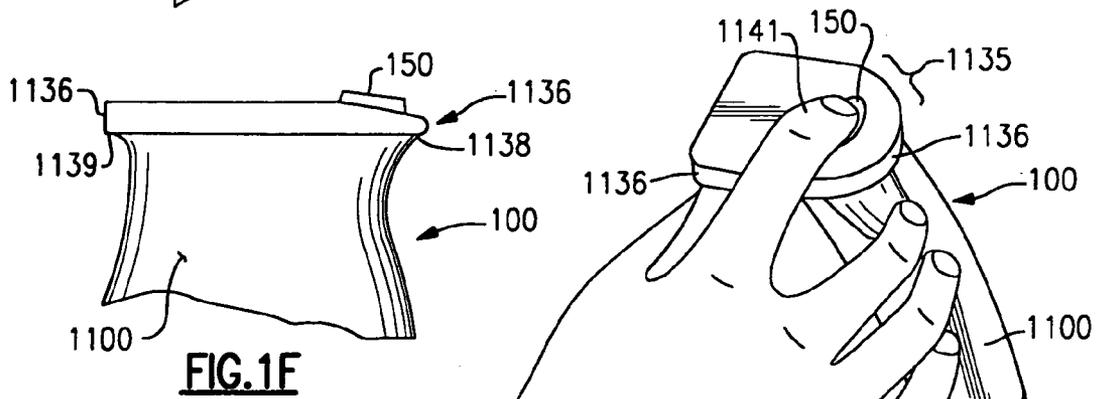
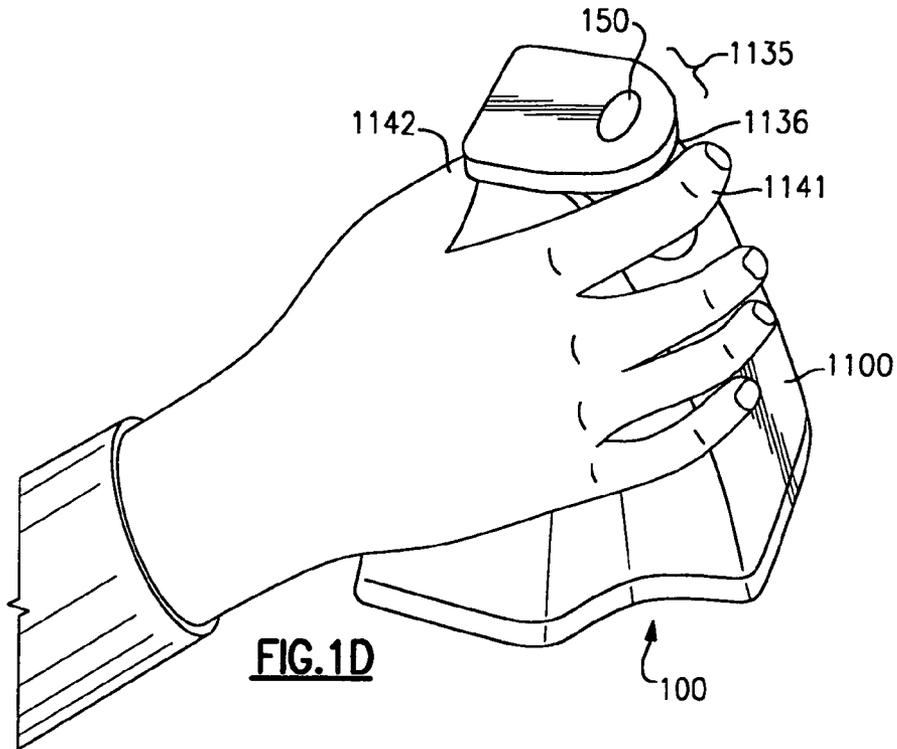
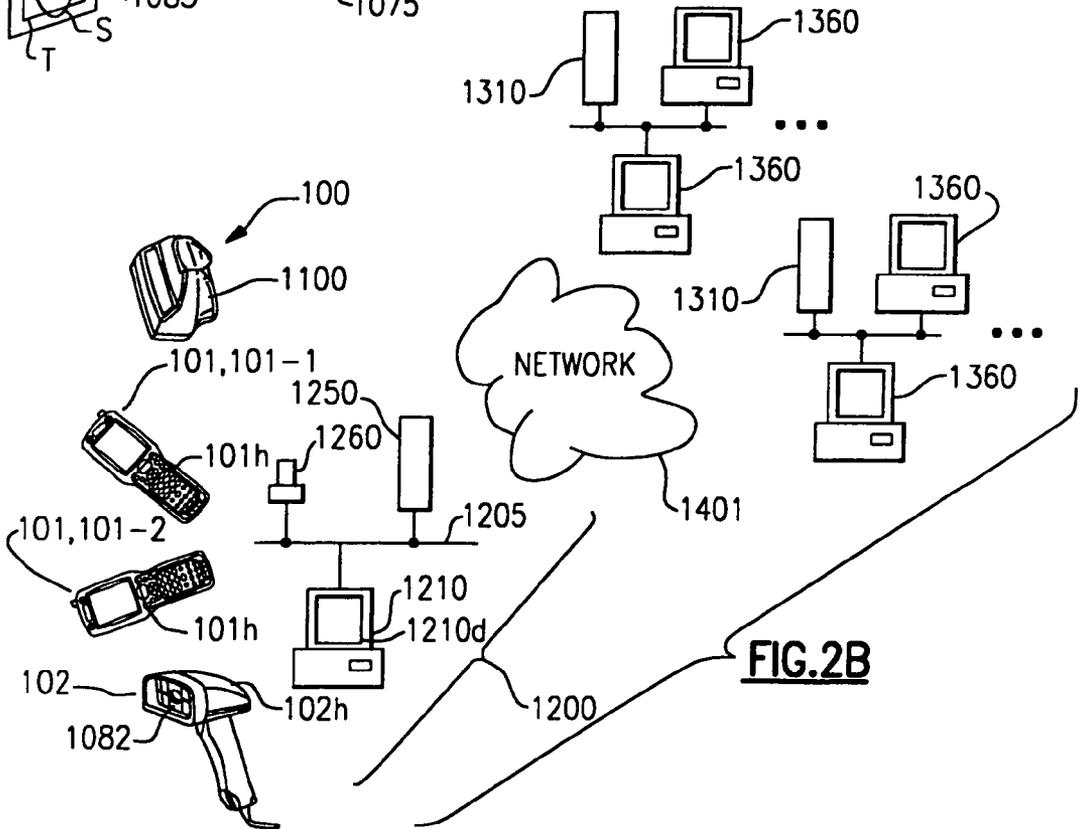
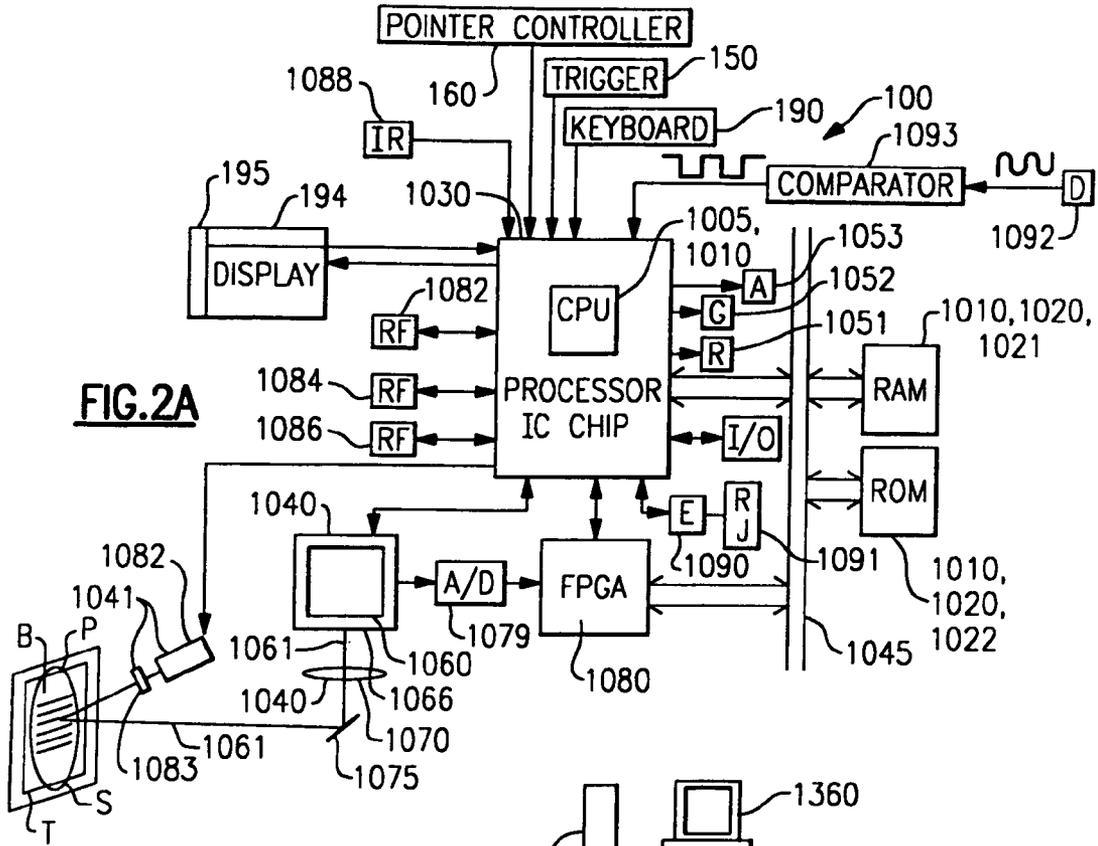


FIG. 6D





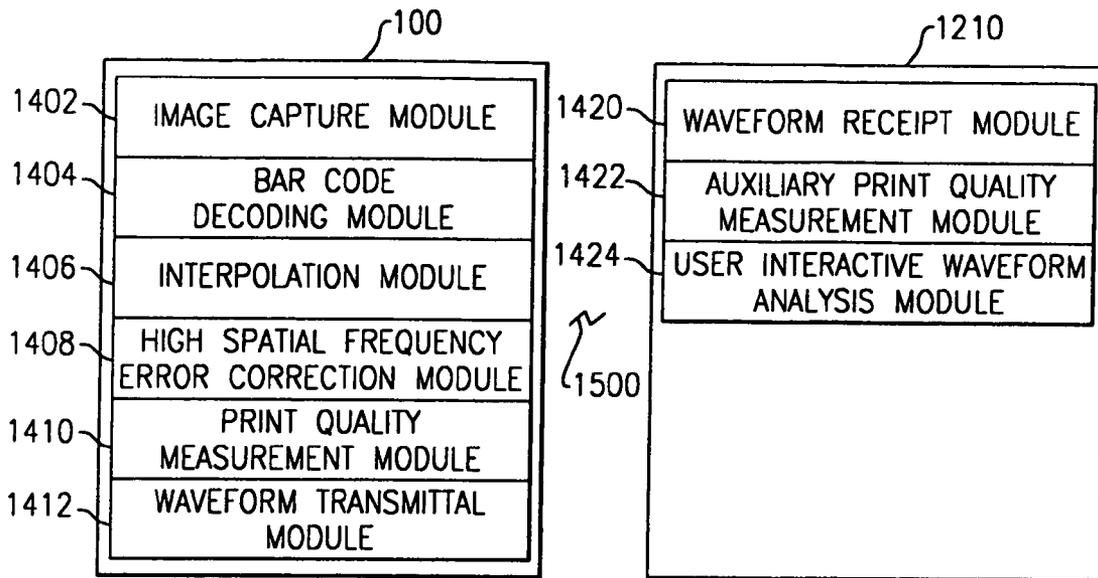
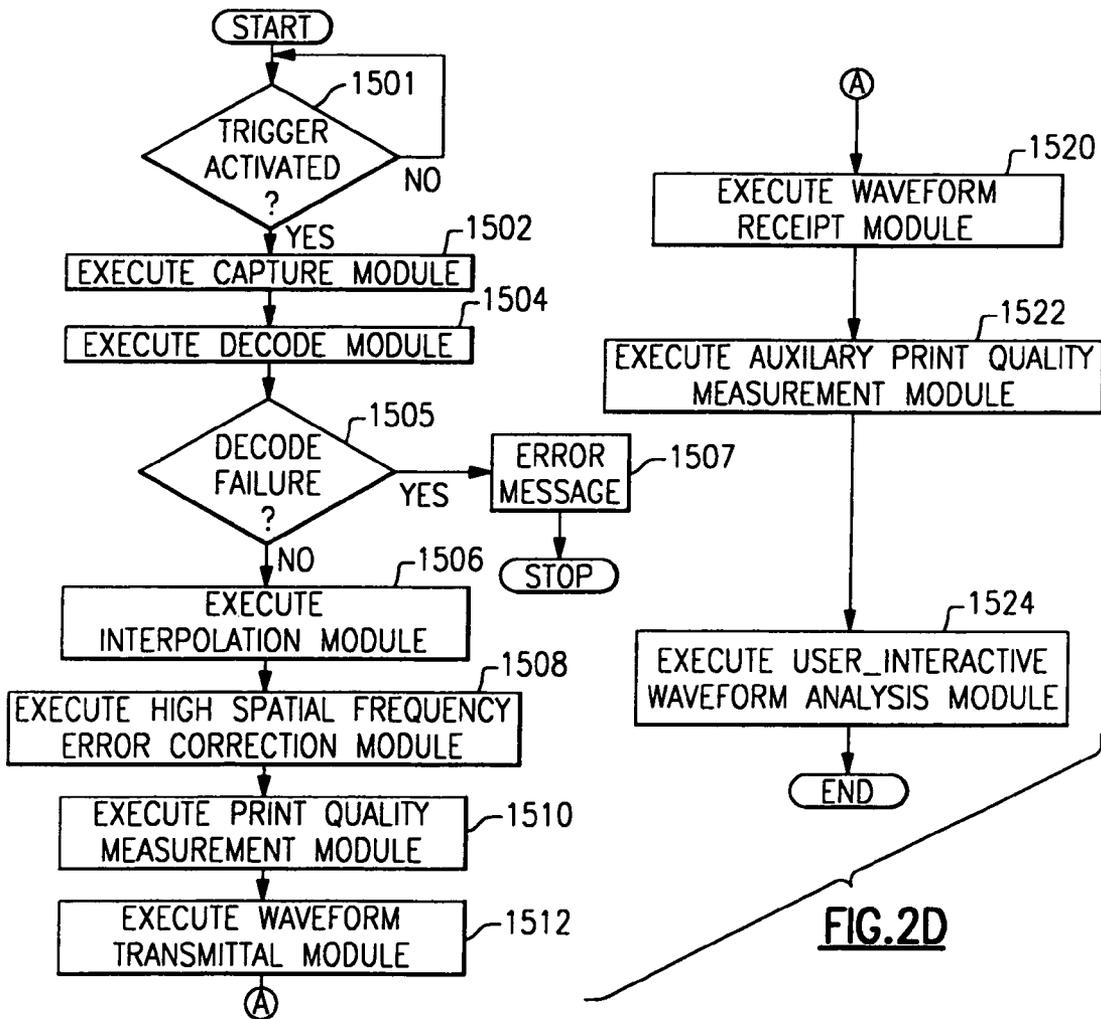


FIG.2C



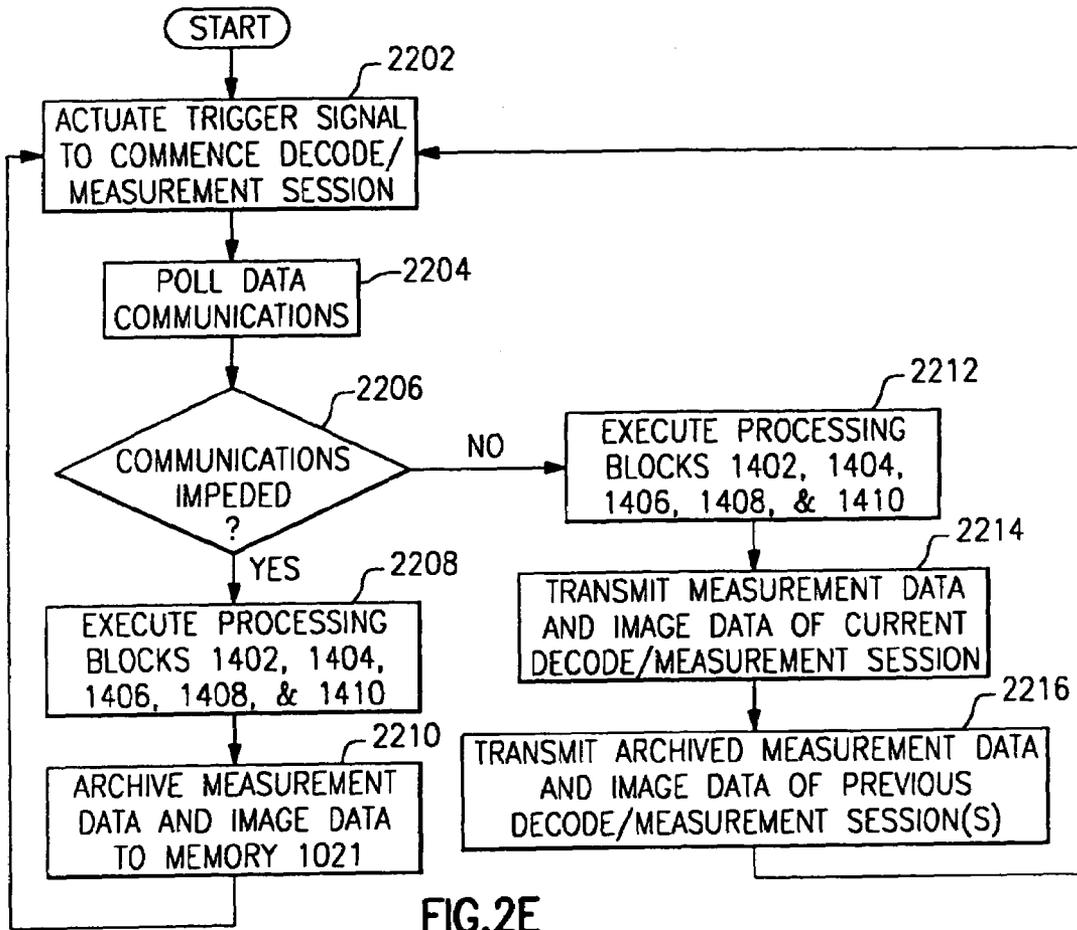


FIG.2E

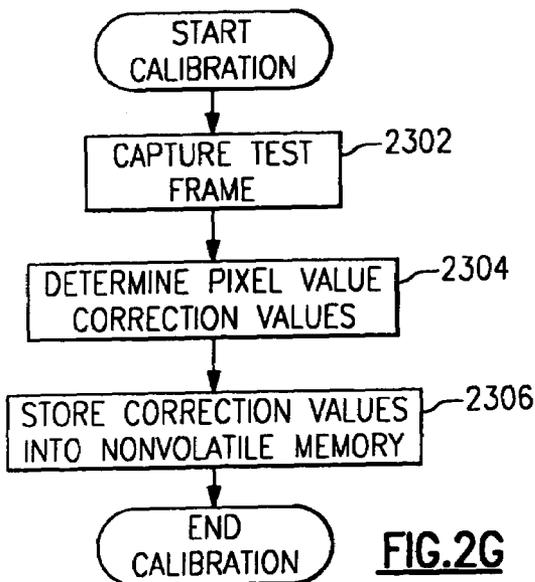


FIG.2G

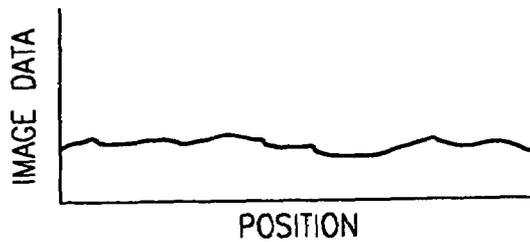


FIG.2F

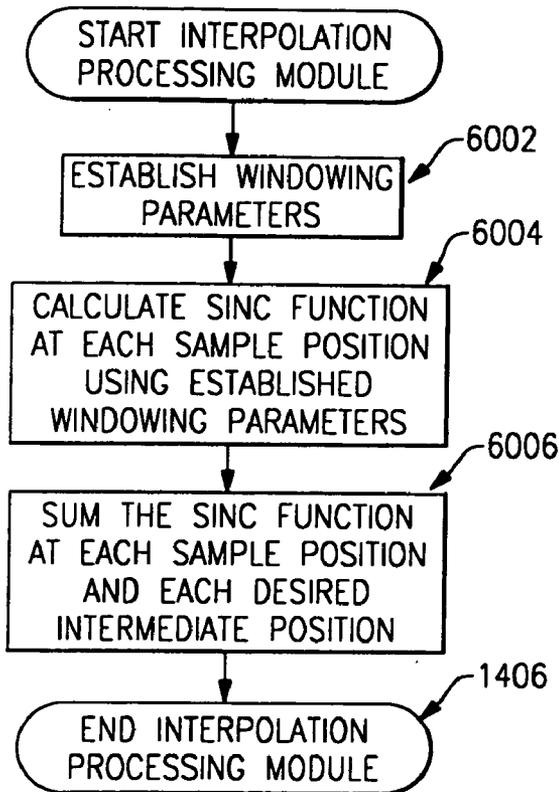


FIG.3A

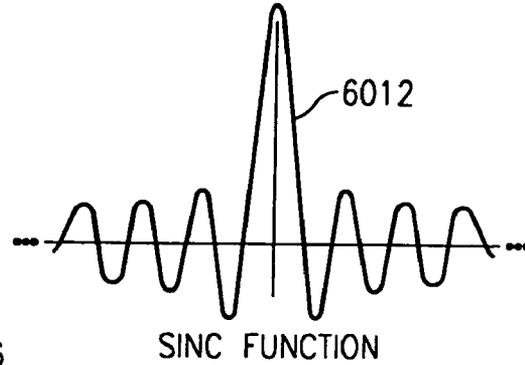


FIG.3H

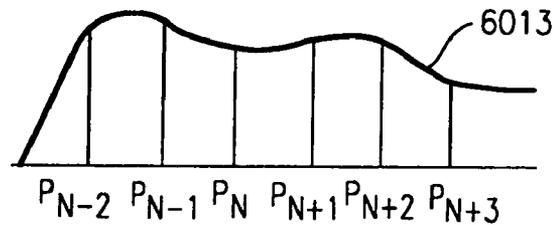


FIG.3I

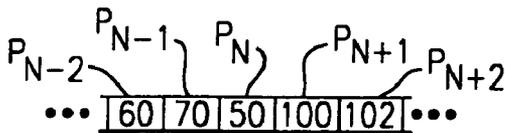


FIG.3K

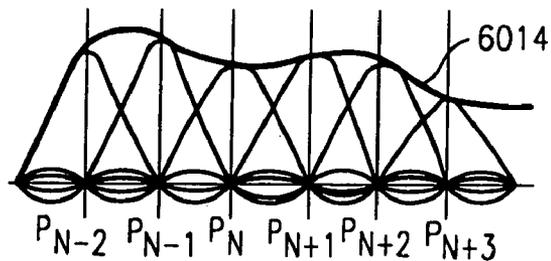


FIG.3J

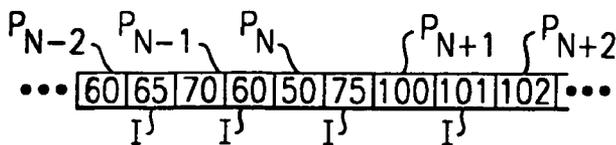


FIG.3L

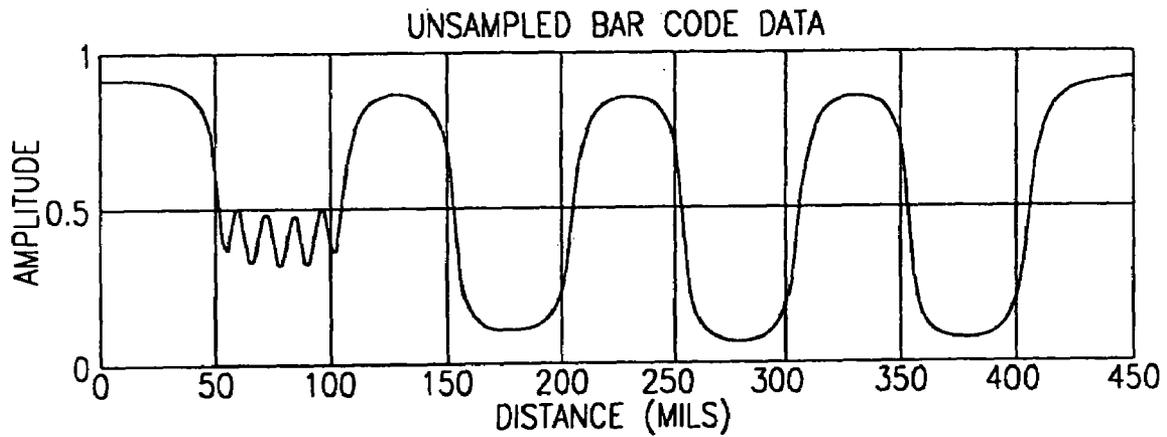


FIG.3B

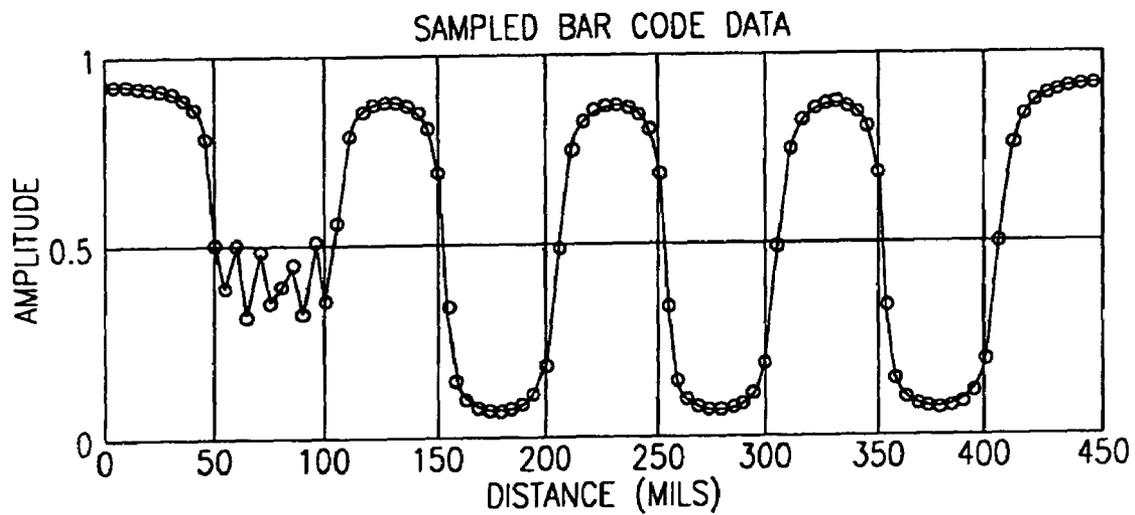


FIG.3C

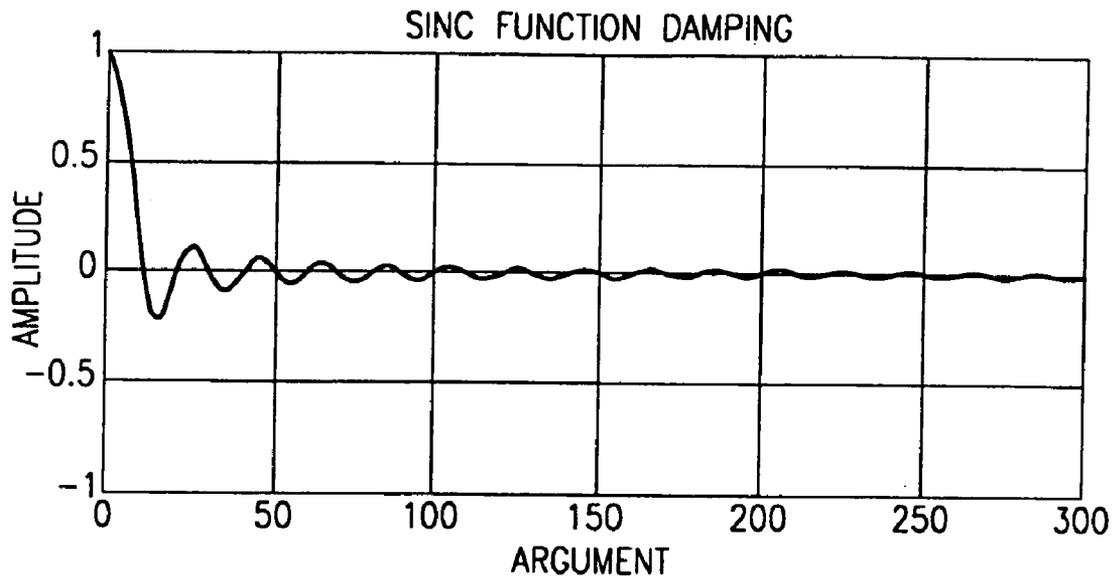


FIG.3D

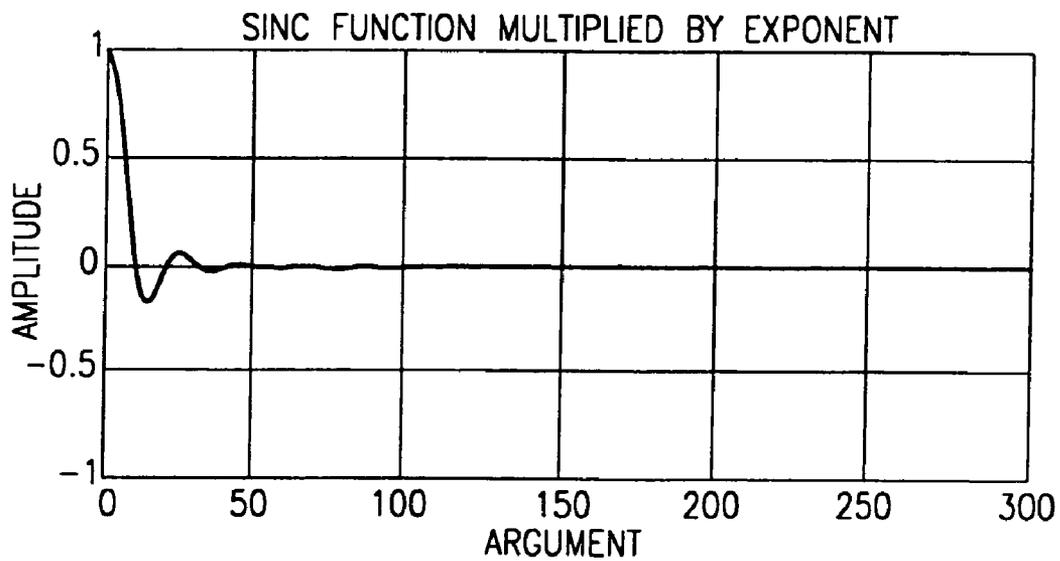


FIG.3E

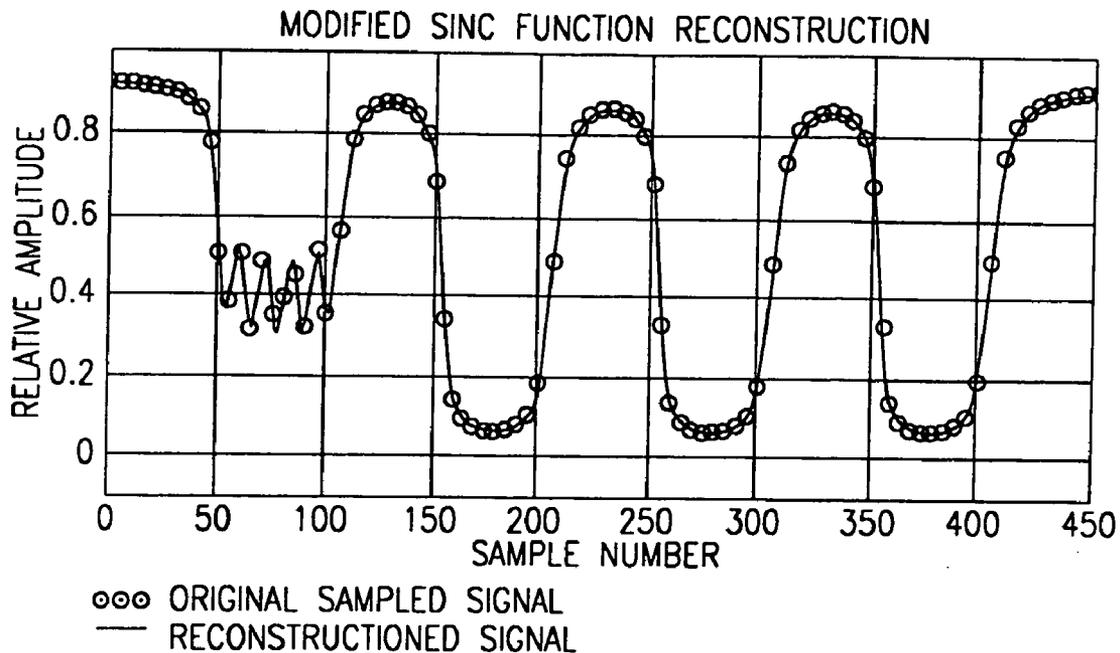


FIG.3F

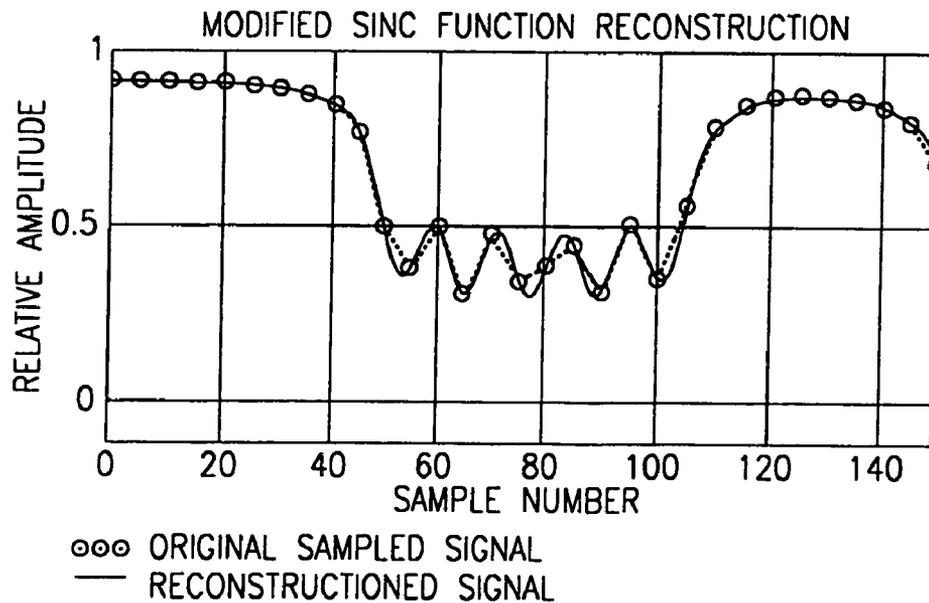


FIG.3G

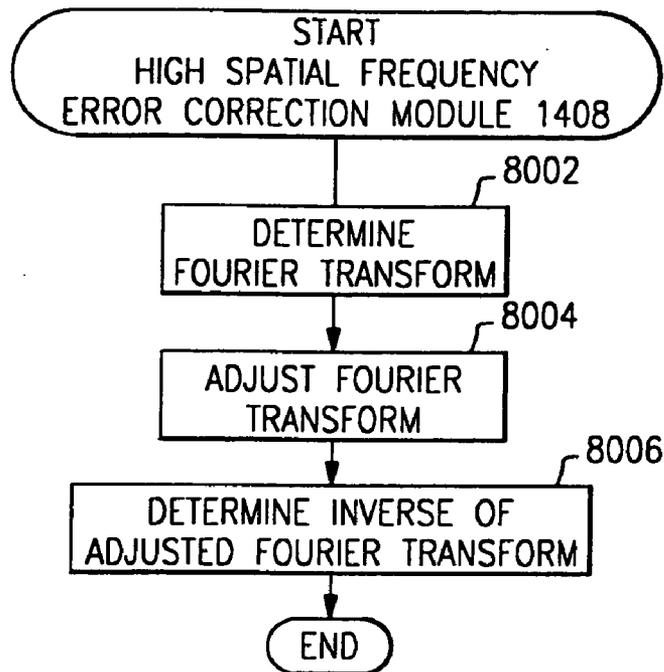


FIG.4A

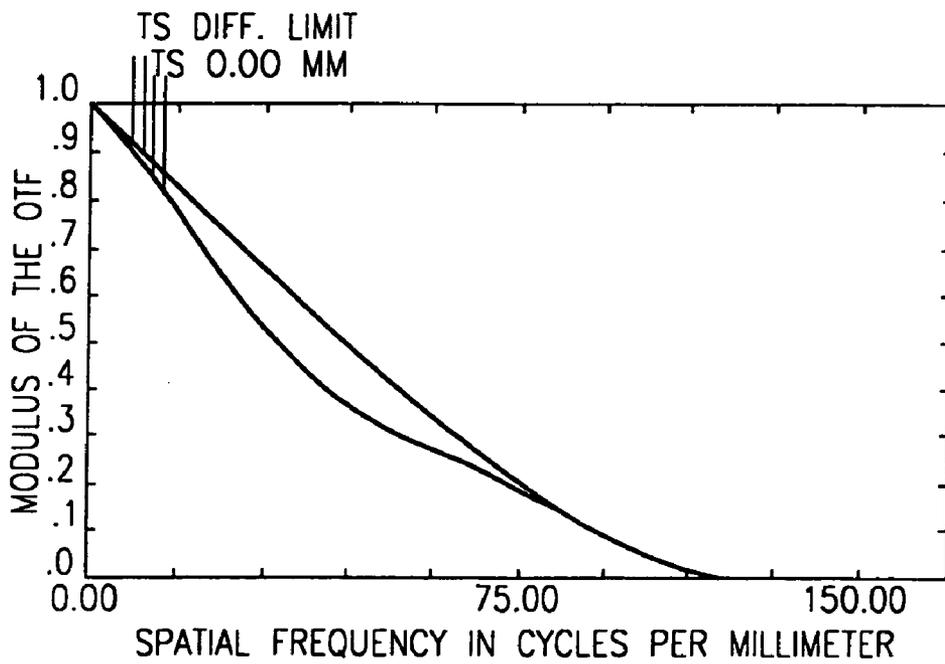
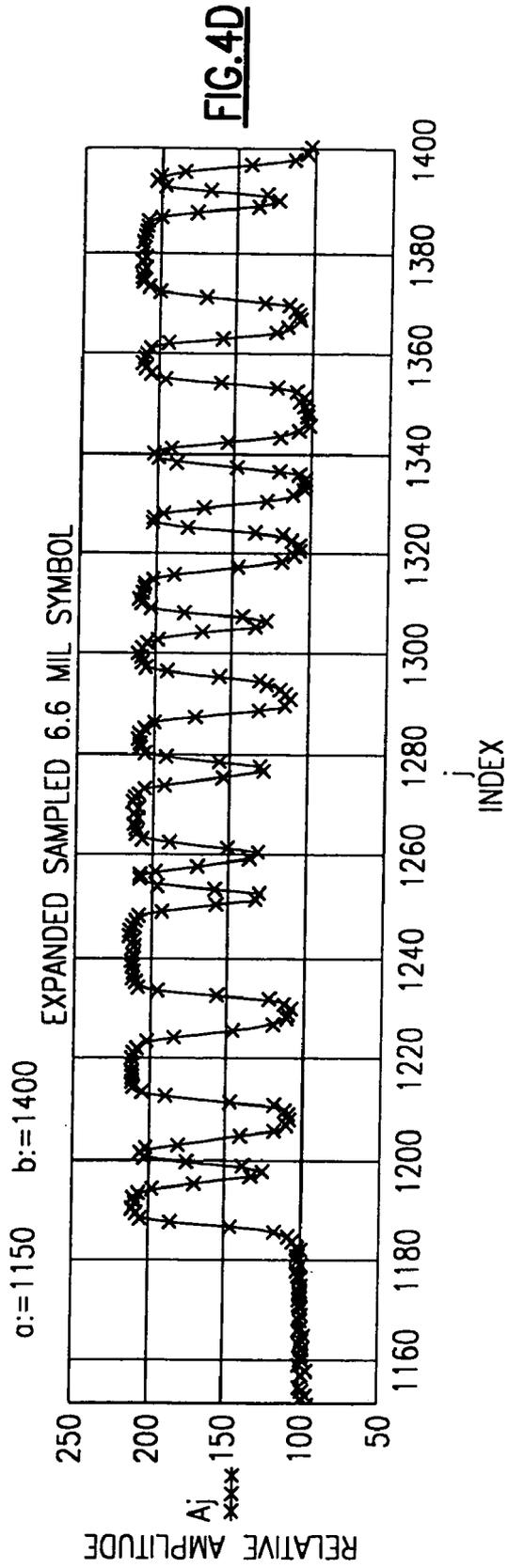
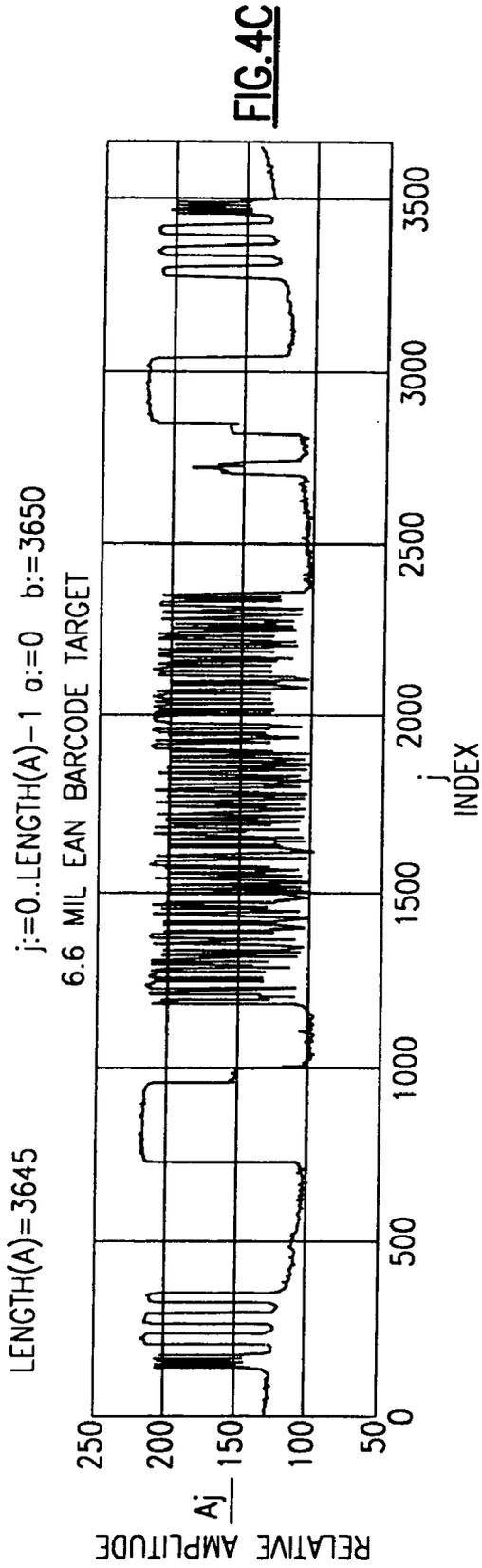
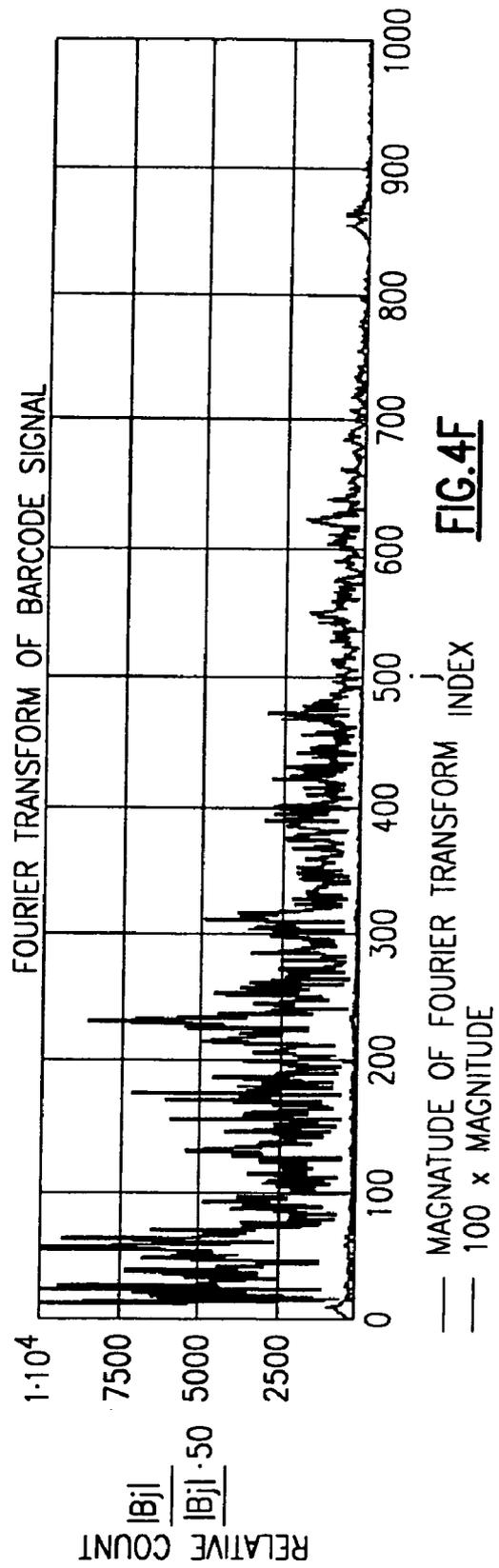
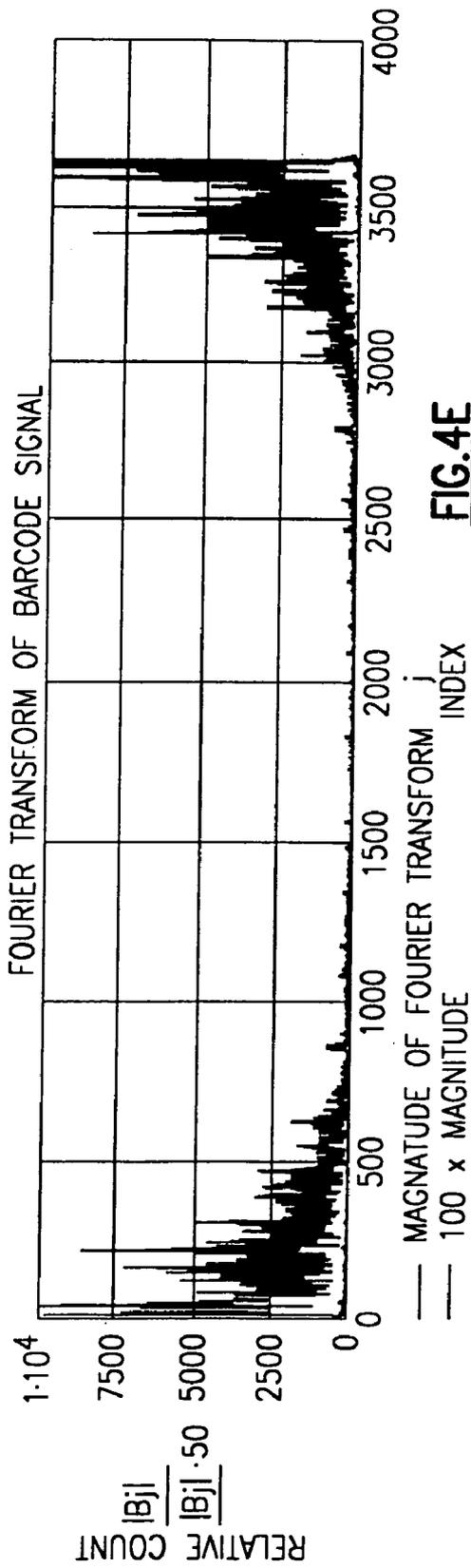
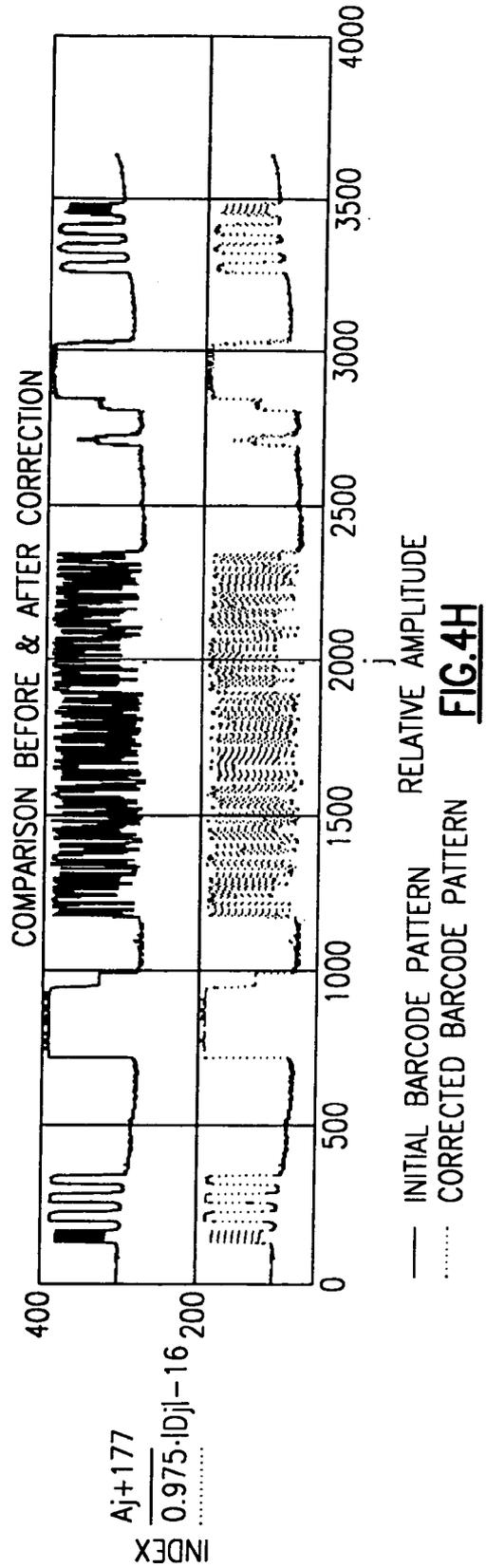
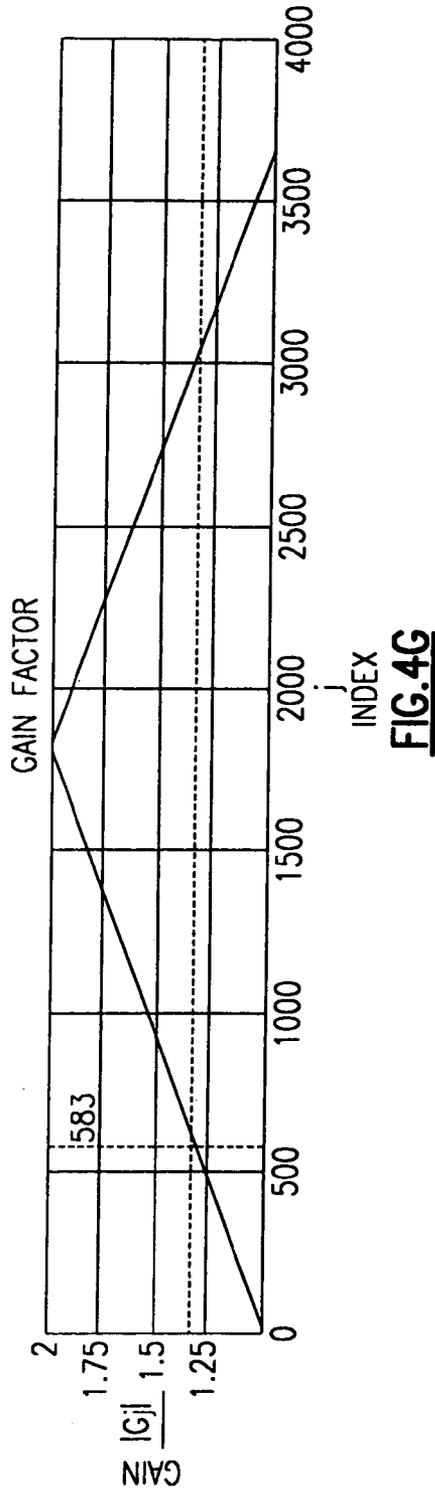
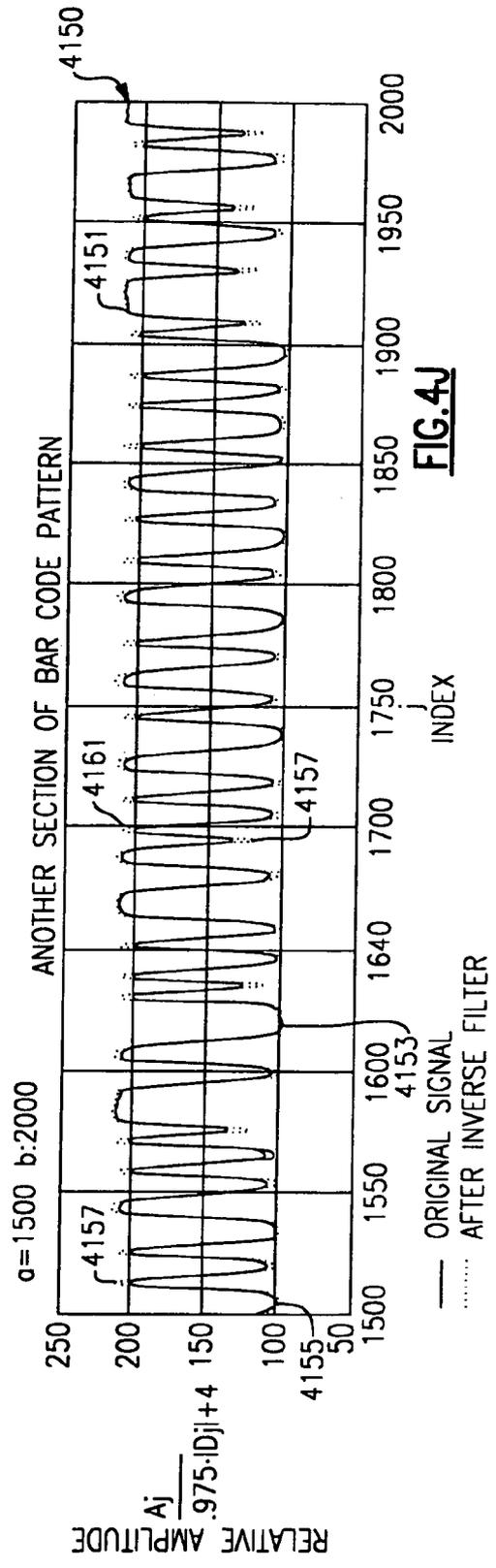
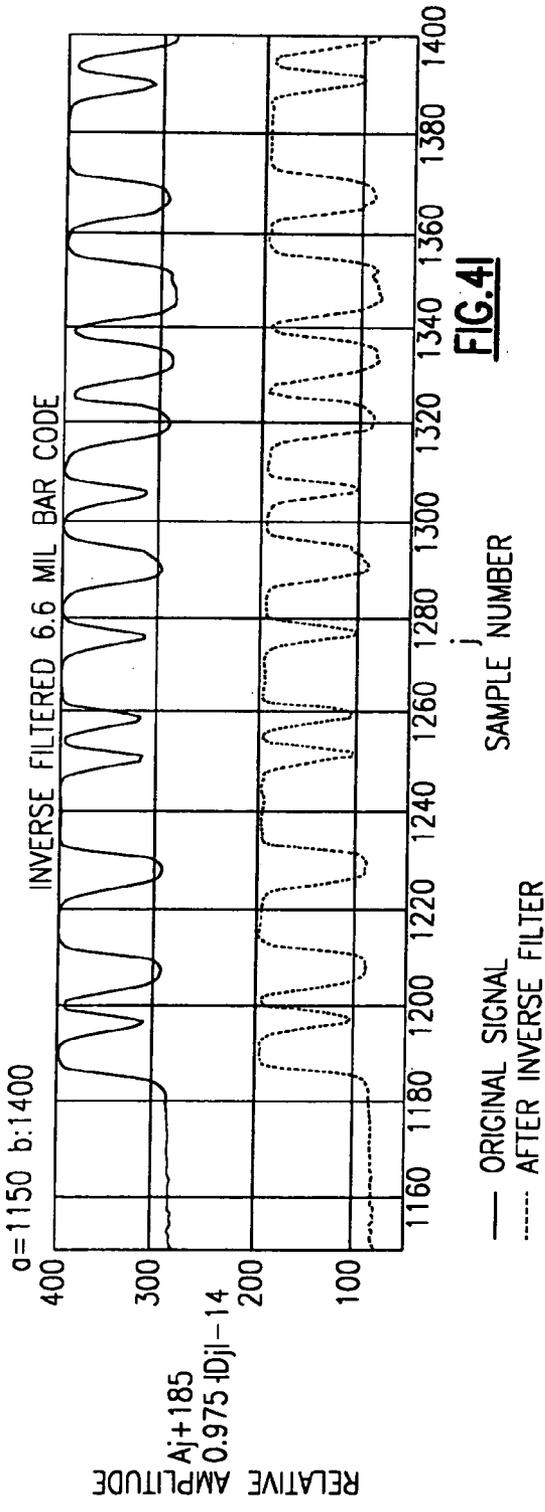


FIG.4B









$$\frac{A_j + 185}{0.975 \cdot |D_j| - 14}$$

$$\frac{A_j}{.975 \cdot |D_j| + 4}$$

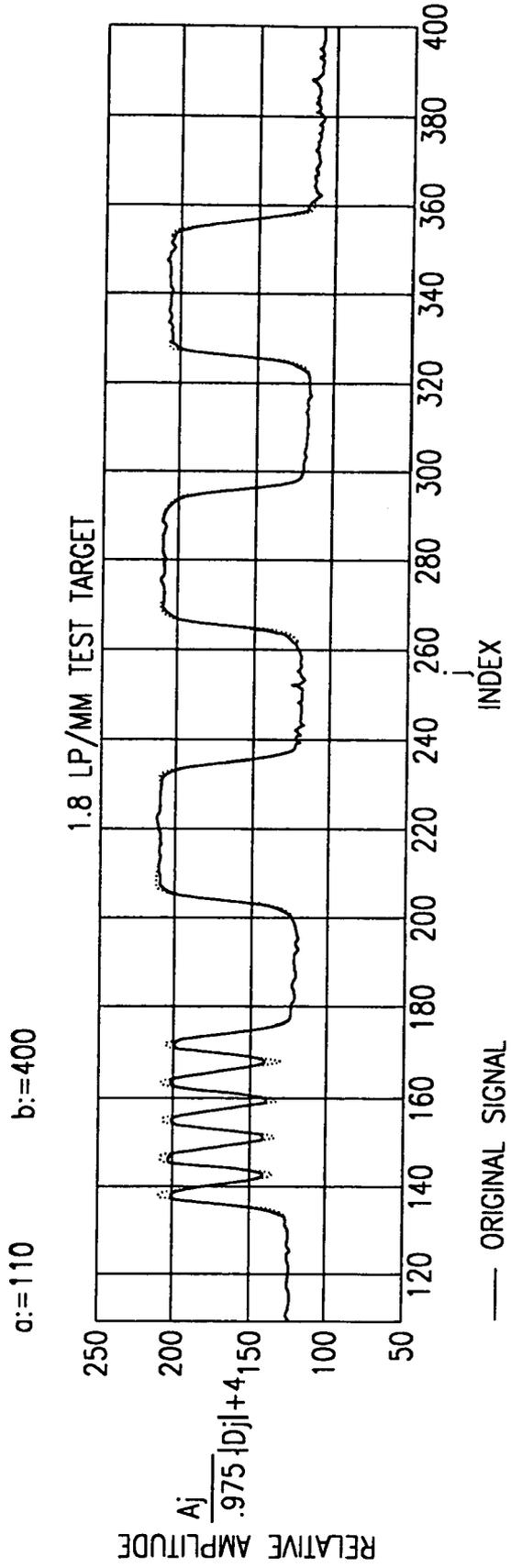
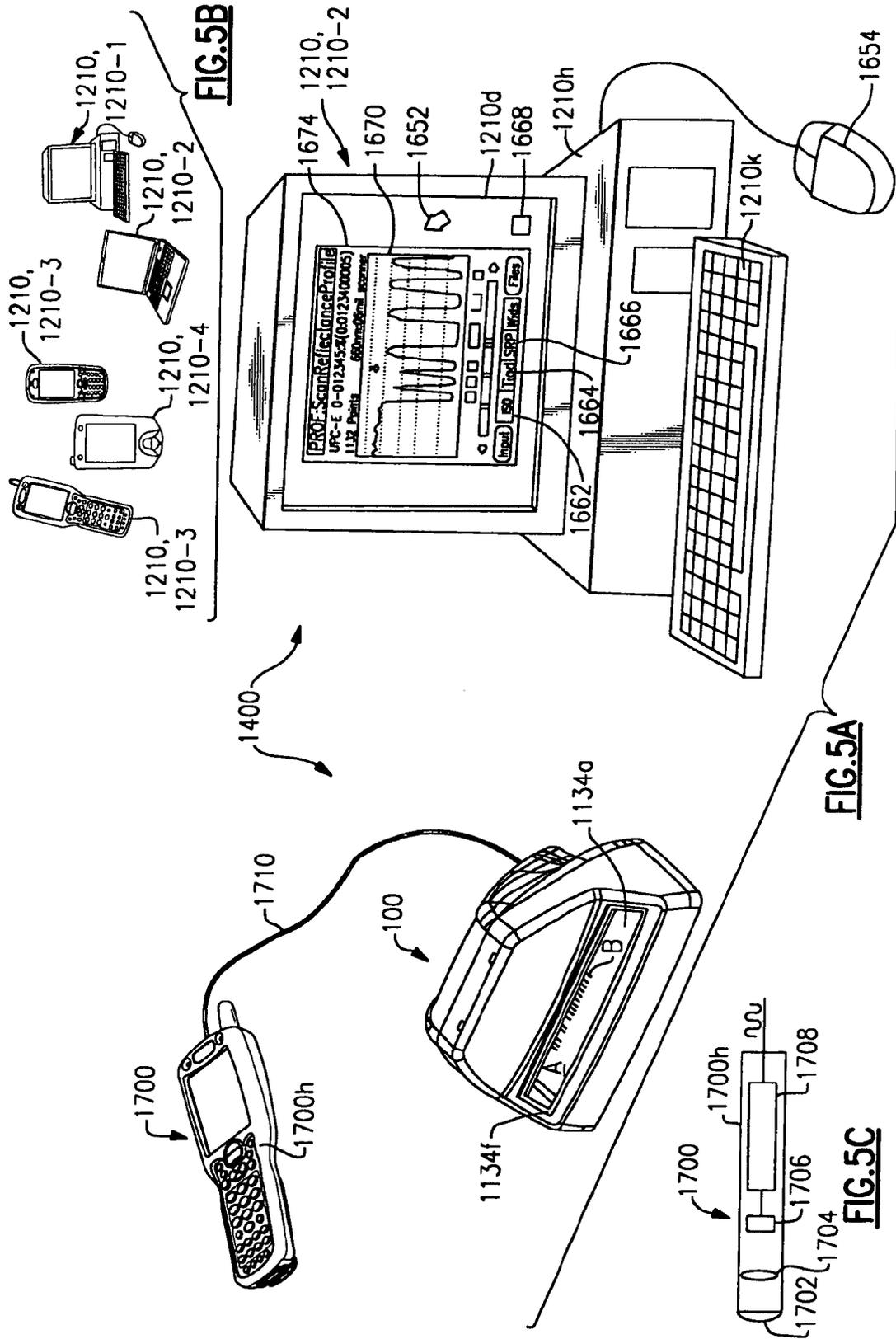


FIG. 4K



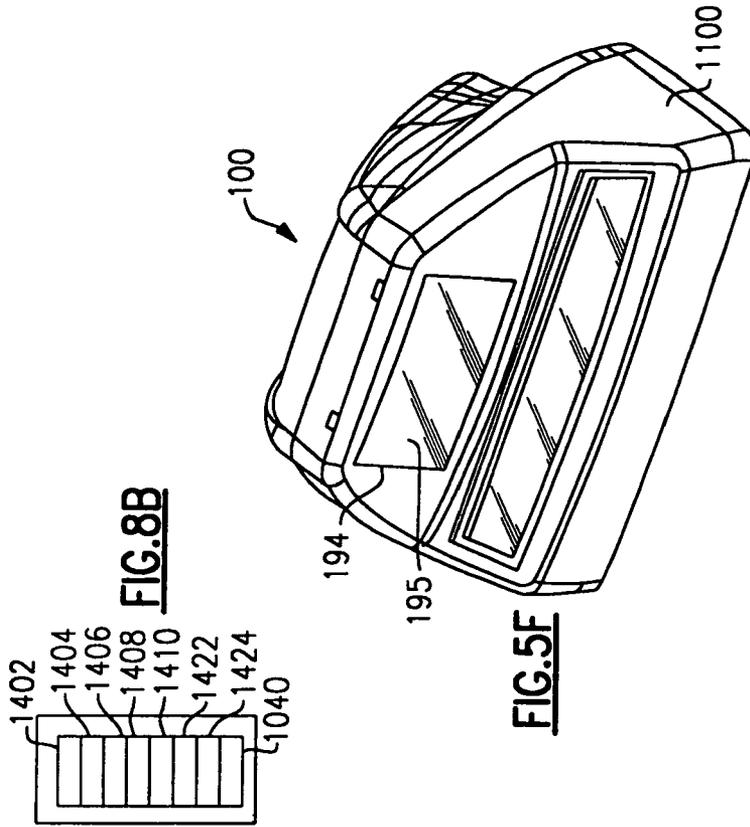


FIG. 5F

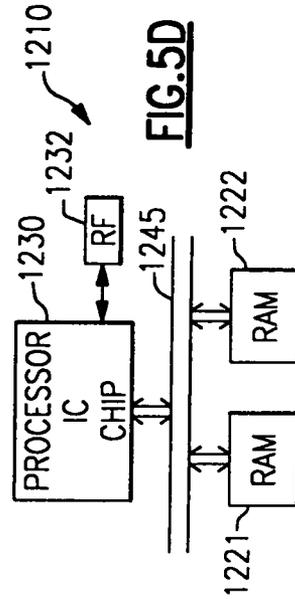


FIG. 5D

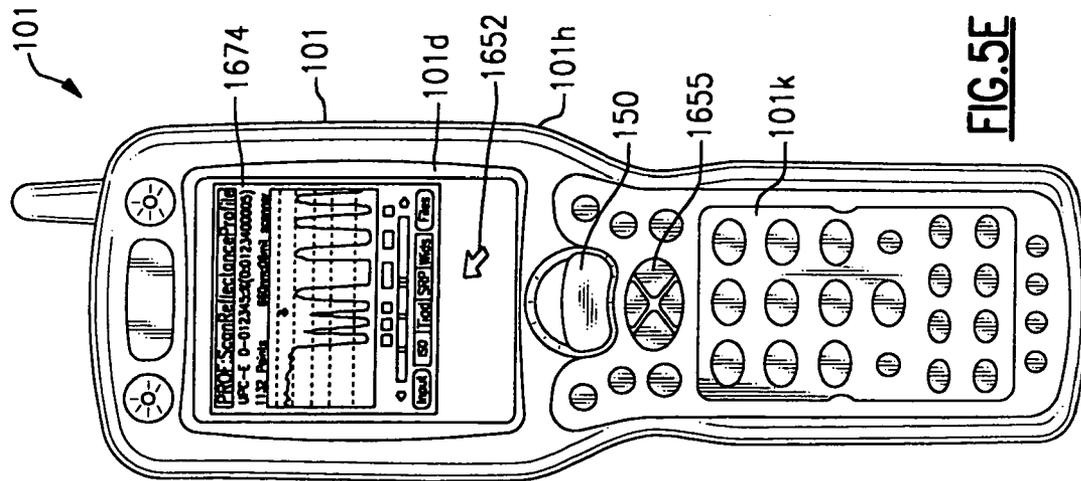


FIG. 5E

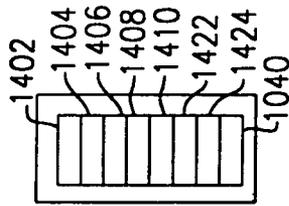


FIG. 8B

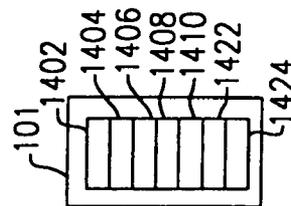
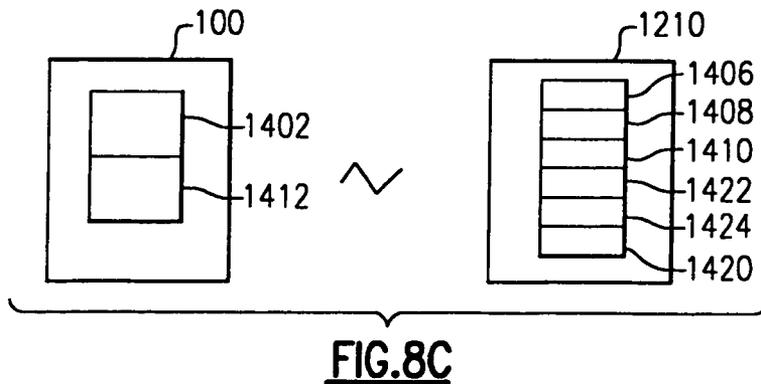
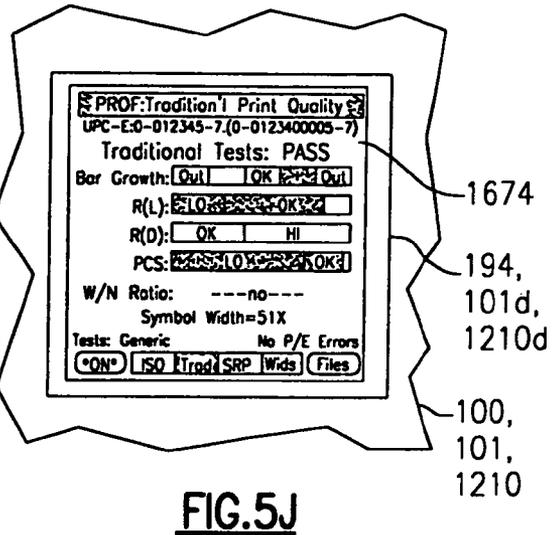
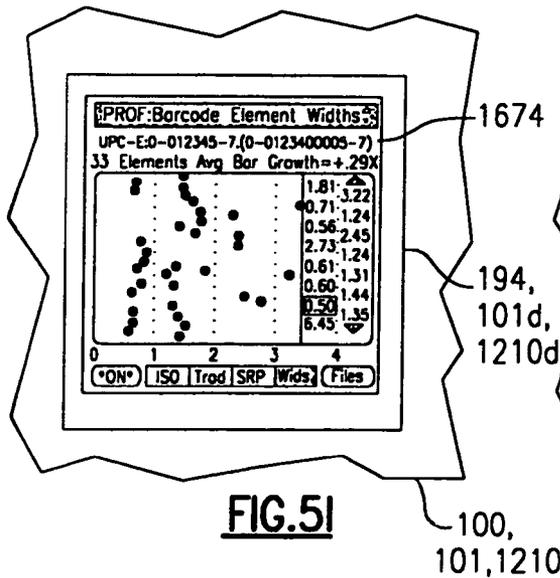
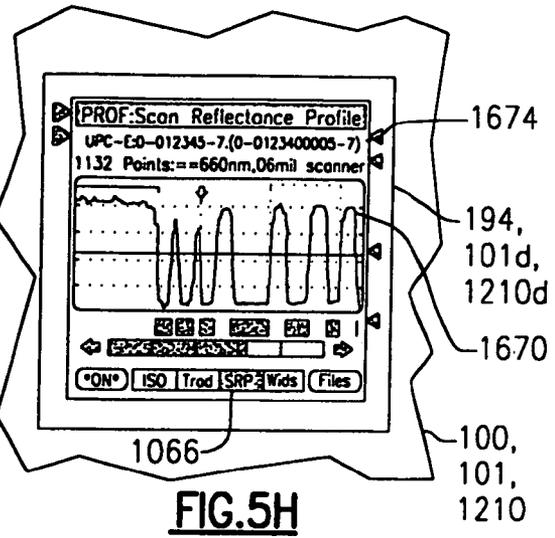
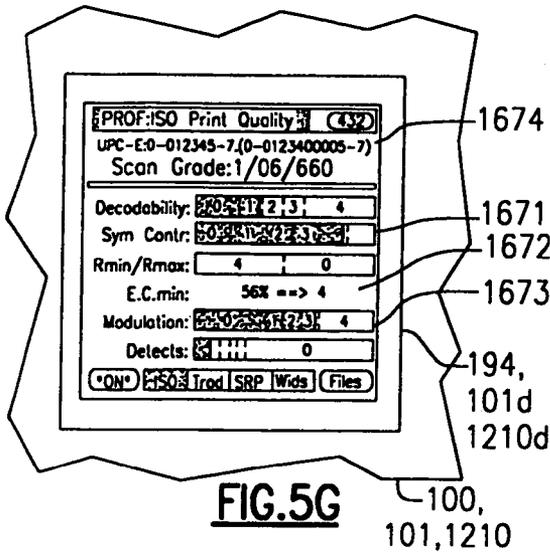


FIG. 8A



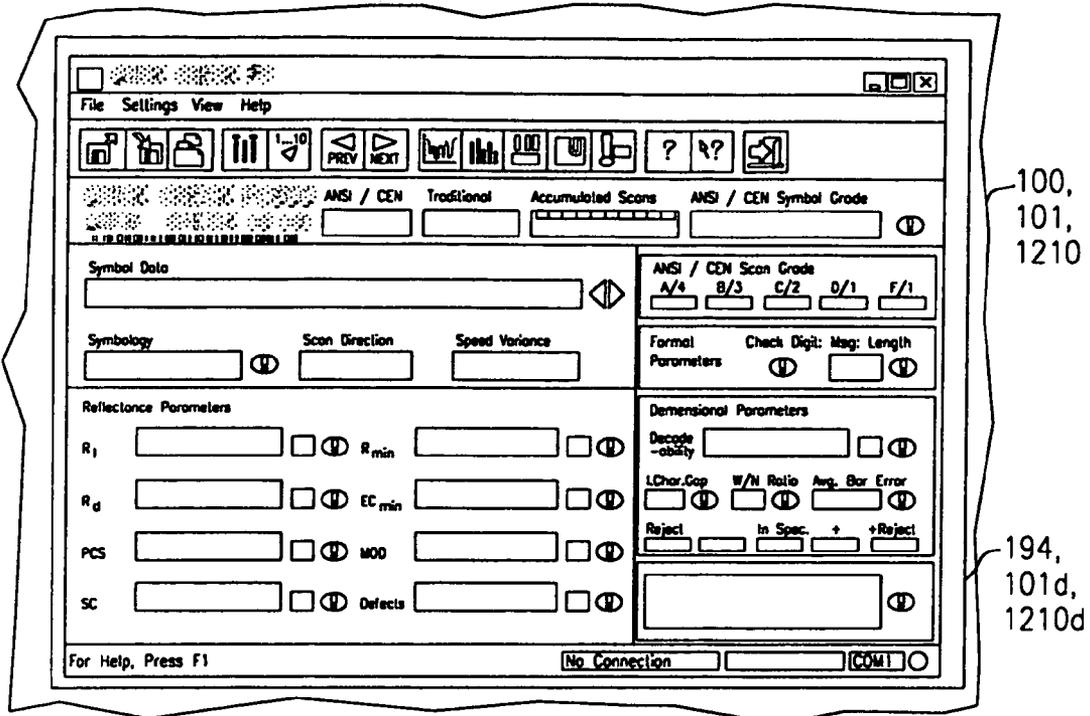


FIG.5K

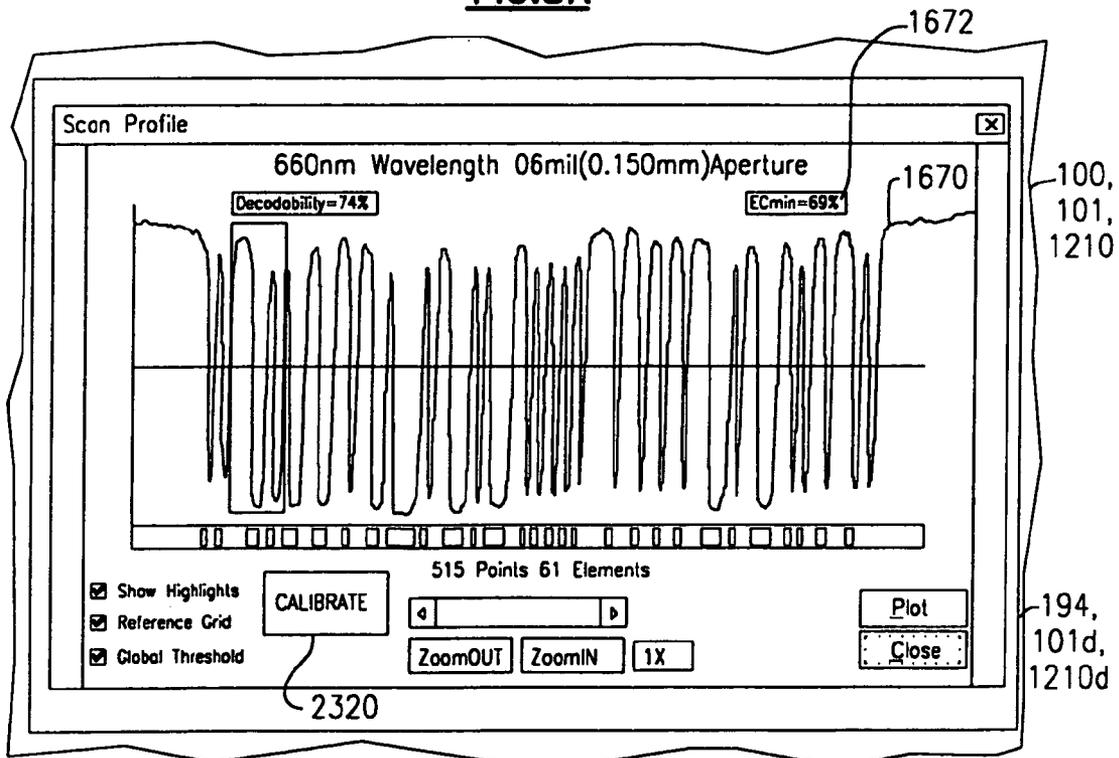


FIG.5L

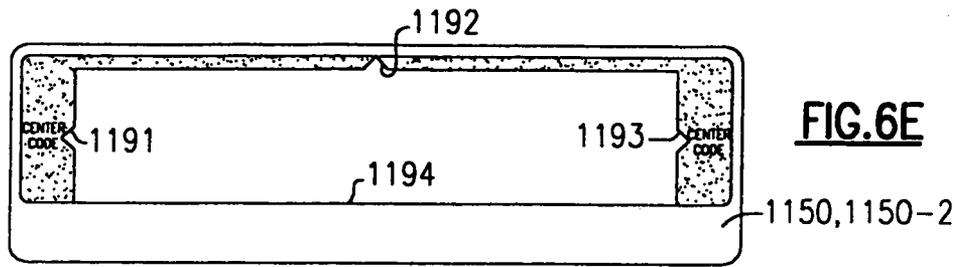


FIG. 6E

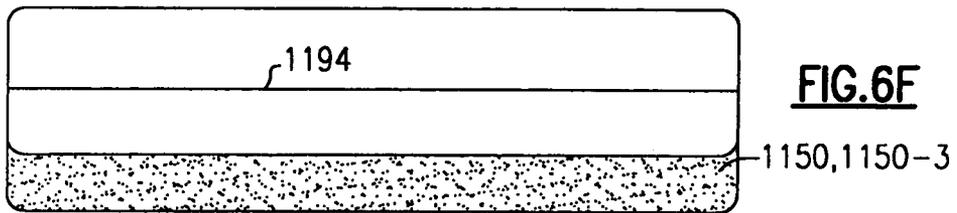


FIG. 6F

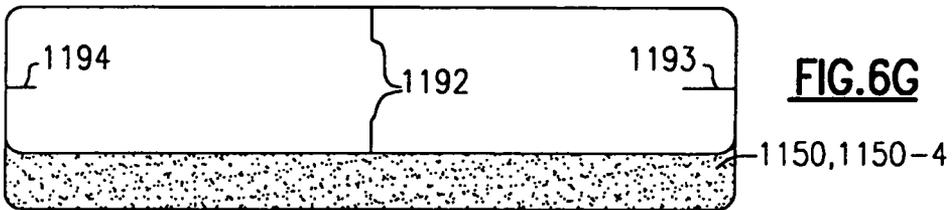


FIG. 6G

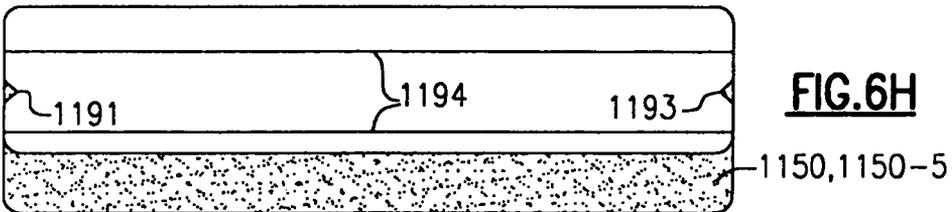


FIG. 6H

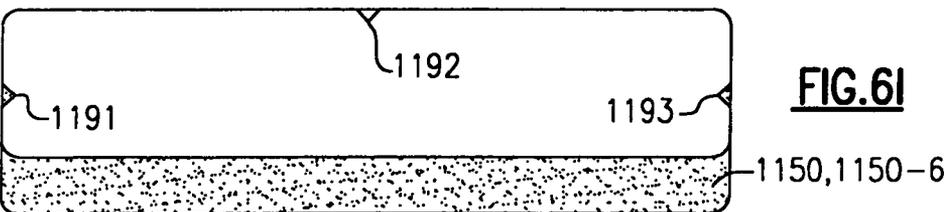


FIG. 6I

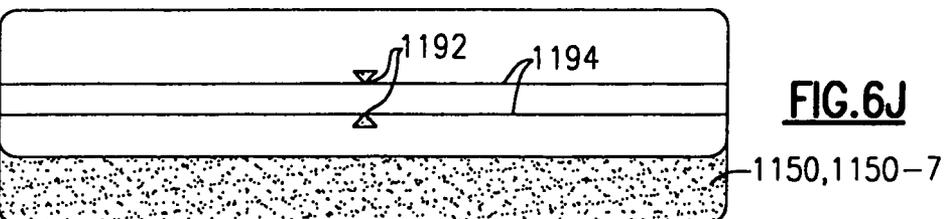


FIG. 6J

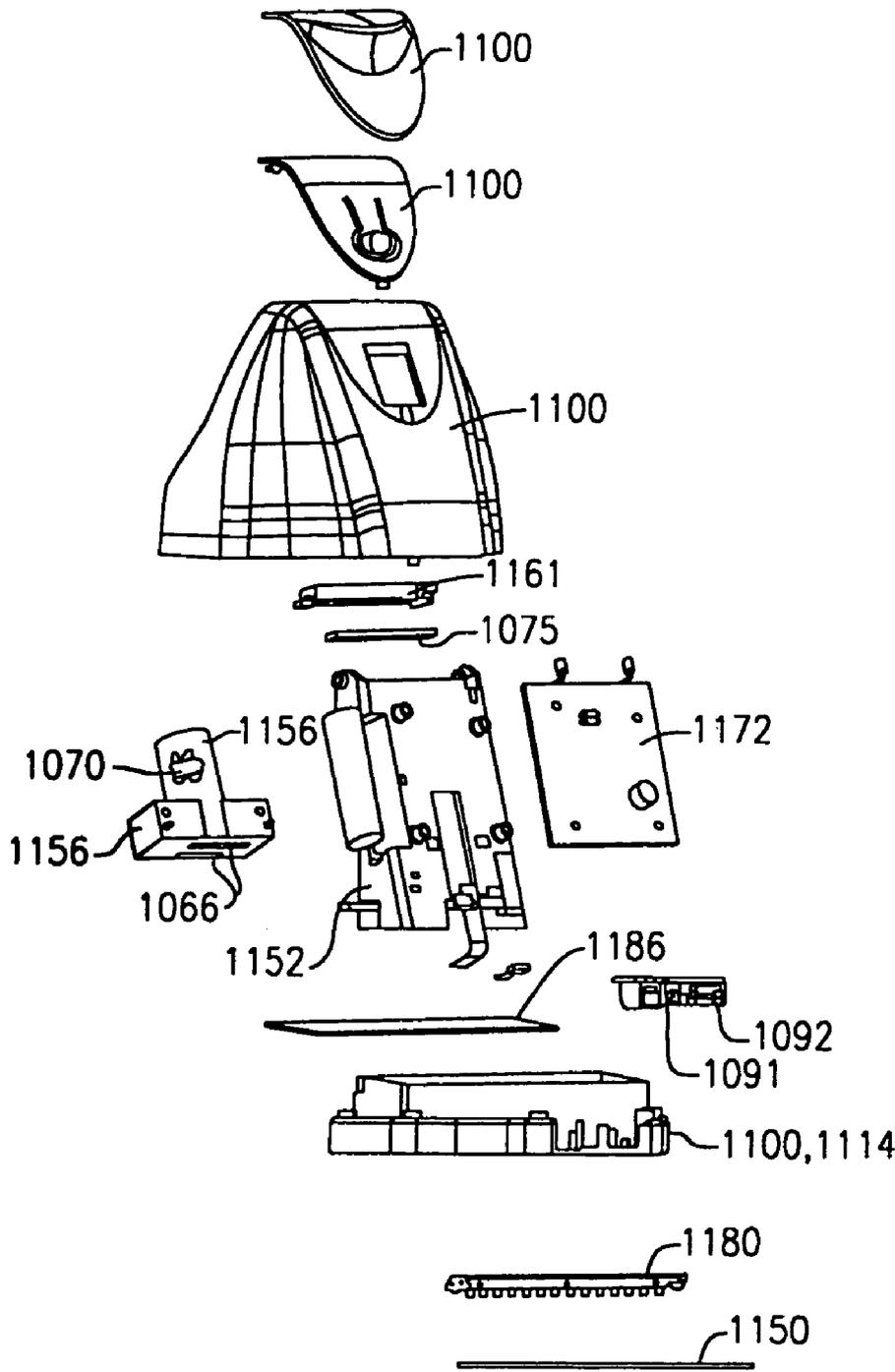


FIG. 6K

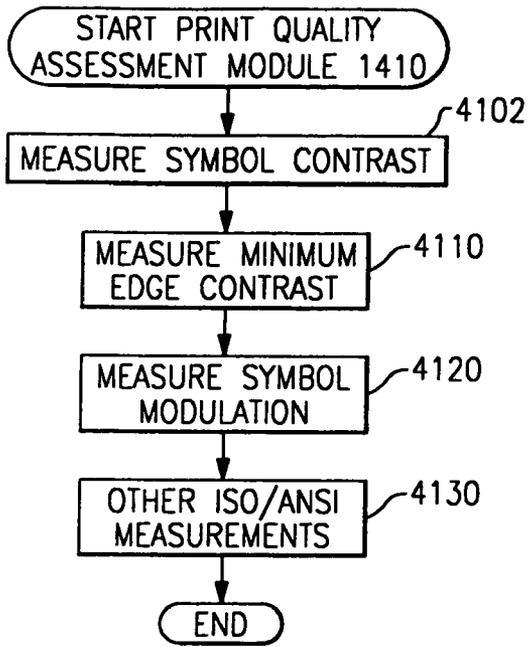


FIG. 7A

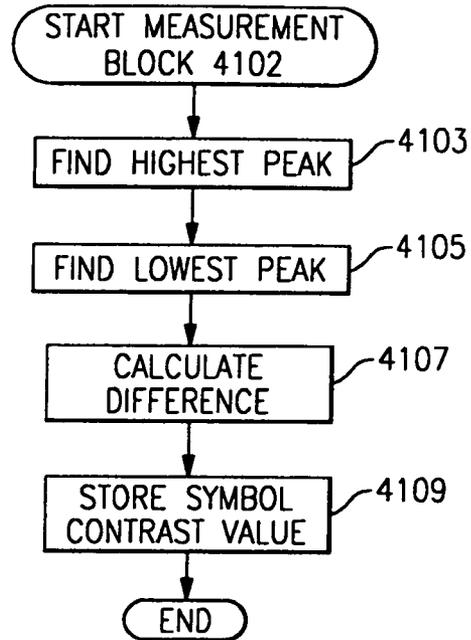


FIG. 7B

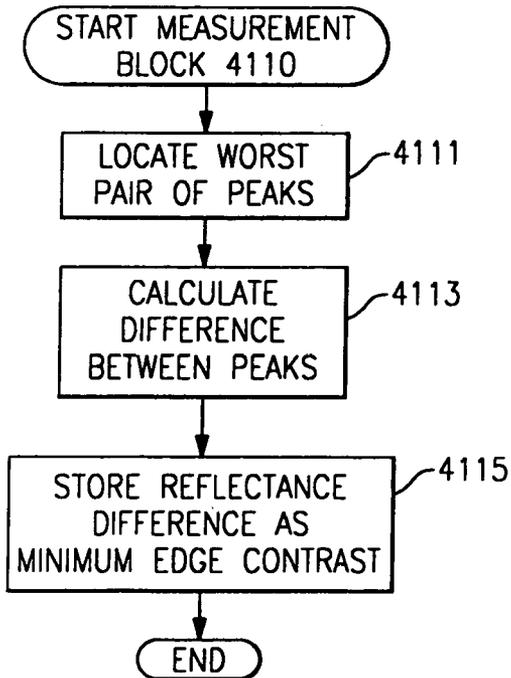


FIG. 7C

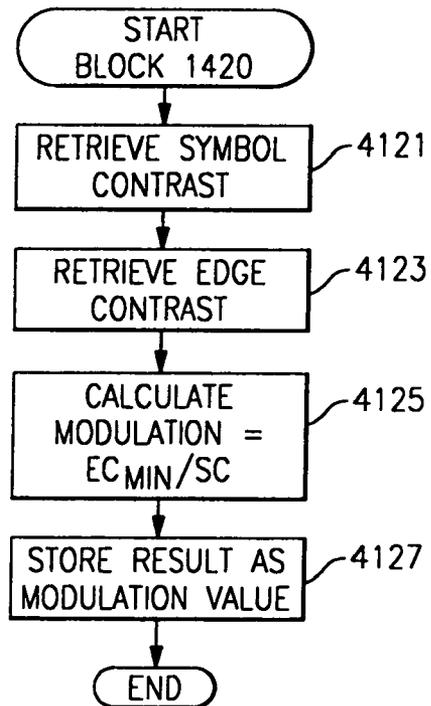


FIG. 7D

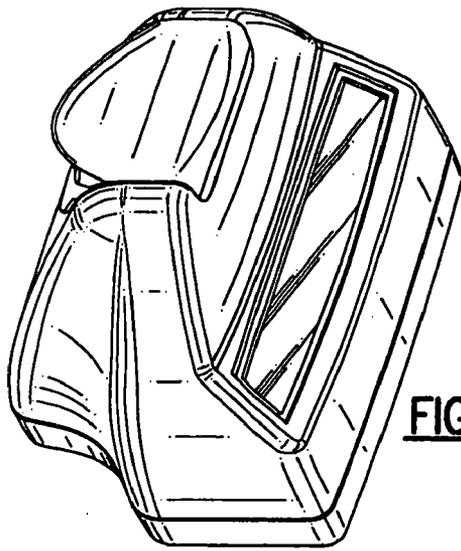


FIG. 9A

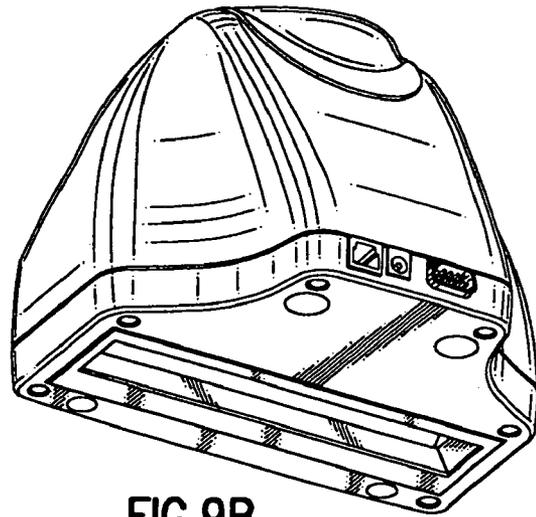


FIG. 9B

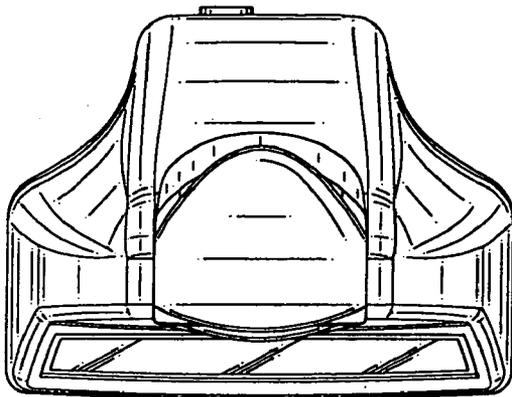


FIG. 9C

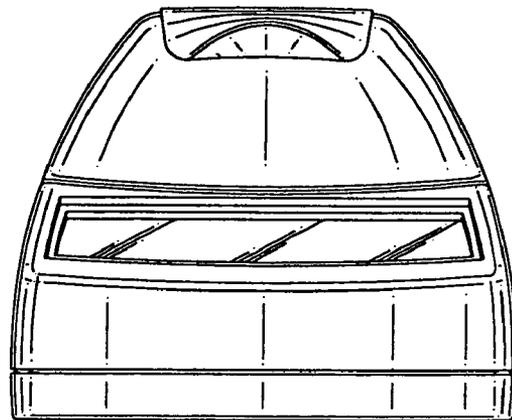


FIG. 9D

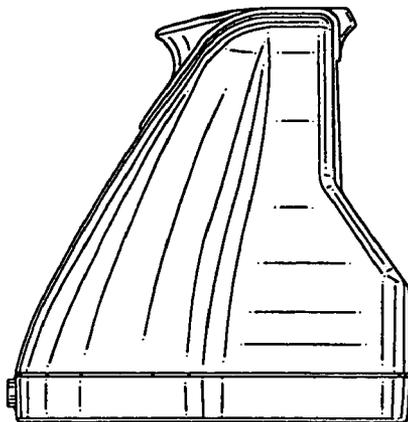


FIG. 9E

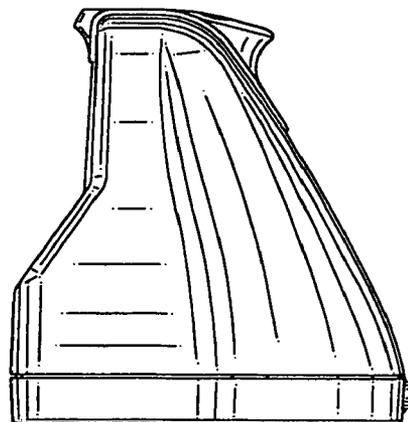


FIG. 9F

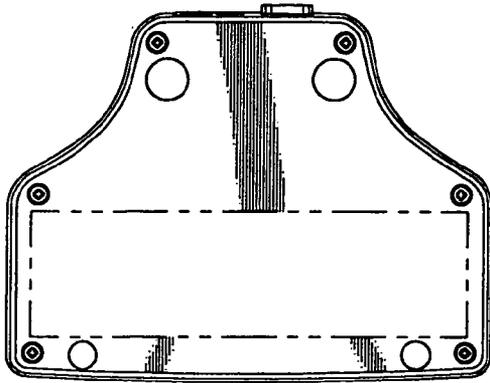


FIG. 9G

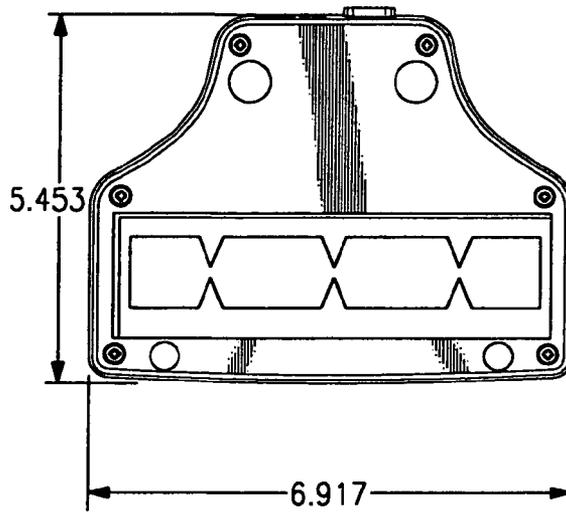


FIG. 9H

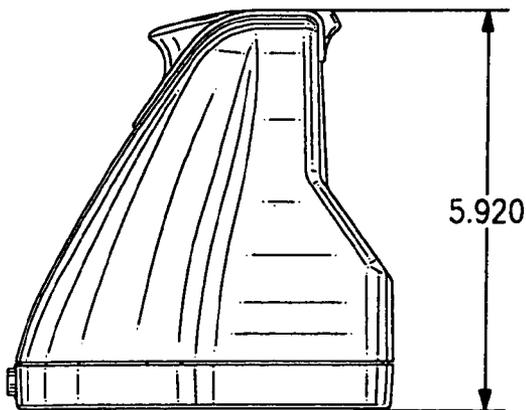


FIG. 9I

DEVICE AND SYSTEM FOR VERIFYING QUALITY OF BAR CODES

FIELD OF THE INVENTION

The invention relates generally to registers in general and particularly to optical readers.

BACKGROUND OF THE INVENTION

Bar codes are available in a variety of symbologies. One dimensional symbologies include Code 128, Code 39, Interleaved 2 of 5, Codabar, Code 93, Code 11, and MSI. Stacked 1 symbologies include PDF, Code 16K and Code 49. 2D symbologies include Aztec, Datamatrix, and Qcode. Perhaps the most omnipresent bar code symbology is the 1D symbology known as UPC/EAN. UPC/EAN bar codes are standardly used to mark retail products throughout North America, Europe and several other countries throughout the worlds.

Numerous factors can lead to a bar code being unreadable. A bar code symbol can become degraded from extended use, for example, if a wand or other contact reader is swiped across a bar code numerous times. Dust or debris collecting on a bar code, as in a factory or other industrial setting can also negatively affect the capacity of a bar code symbol to be decoded by a reader. The most prevalent forms of degradation actually occur during the printing process, for example ink smearing, improper encodation of the required information, use of improper ink resulting in insufficient bar to space contrast and improperly dimensioned photographic masters. The type of bar code reader being used to read a symbol also has an impact on readability. High quality bar code readers having improved processing functionality and/or improved hardware are able to decode bar code symbols that other bar code readers cannot. Another factor affecting a bar code symbol's capacity to be decoded is the print quality of the bar code symbol. Bar codes that are printed in accordance with high quality standards can withstand degradation such as caused by use or debris accumulation, and can be read by a variety of bar code readers from high to low quality.

Because bar code print quality has an enormous impact on the capacity of a bar code symbol to be successfully decoded, it is advantageous for users of bar codes such as bar code symbol providers, retail product manufacturers, suppliers, shippers, merchants, and hospitals to monitor the quality of printed bar codes prior to a marked article being circulated for sale or use. The America National Standards Institute (ANSI) Specification "Bar Code Print Quality Guideline" X3.182-1990 established guidelines for verifying bar code symbol print quality. Standards for verifying bar code symbol print quality are also provided in standards promulgated jointly by the International Standards Organization (ISO) and the International Electrotechnical Commission ("IEC"); namely Standard ISO/IEC 15416, "Automatic identification and data capture techniques—Bar code print quality test specification—Linear symbols," a bar code print quality test specification for linear symbols, and ISO/IEC 15415, "Automatic identification and data capture techniques—Bar code print quality test specification—Two dimensional symbols" establishes guidelines for verifying 2D bar code symbol print quality, a bar code print quality specification for two dimensional symbols. According to the above referenced Standards, bar code symbols may be subject to several quality measurements and may be allocated a numerical or letter grade ranging from zero (F) to 4.0

(A). A higher grade means that the bar code is more likely to be successfully decoded, whereas a lower grade means that the bar code is less likely to be successfully decoded. Historically, the "Quality Specification for the UPC Printed Symbol," published by the Uniform Code Council, Inc. of Dayton Ohio, established guidelines for evaluating UPC Codes.

While standards have been developed for evaluating bar code symbols, the devices available for conducting such evaluations continue to exhibit limitations. For example, some available bar code verification devices are large, bulky and expensive. Others require significant set up and/or calibration operations prior to use. Still other available verification devices have been noted to be difficult to operate.

There is a need for a bar code verification device and system which is convenient to operate, and which overcomes various noted problems with prior art verification devices.

DESCRIPTION OF DRAWINGS

FIGS. 1A–1B are various perspective views of a hand held bar code symbol verification device according to the invention;

FIG. 1C is a perspective view of a verification device having an alignment member of a different style relative to the device depicted in FIG. 1B;

FIG. 1D is a perspective view of a verification device according to the invention being held by an operator, the verification device having an enlarged head portion that aids in the maneuverability of the device;

FIG. 1E is another perspective view of the verification device of FIG. 1D, showing an operator actuating a trigger of the device;

FIG. 1F is a side view of the verification device shown in FIG. 1D;

FIG. 2A is an electro-optical block diagram of a hand held verification device according to the invention in one embodiment;

FIG. 2B is an electrical block diagram of a system network including a hand held verification device and a plurality of host processors including a local host processor and several remote host processor;

FIG. 2C is a schematic diagram showing the integration of various processing modules of the invention in one embodiment;

FIG. 2D is a flow diagram illustrating an ordering of processing modules which may be executed by a verification system according to the invention;

FIG. 2E is a flow diagram illustrating operation of a verification device according to the invention in one mode of operation;

FIG. 2F is a diagram illustrating a set of image data including fixed pattern noise;

FIG. 2G is a flow diagram of a verification device according to the invention in a calibration mode of operation;

FIG. 3A is a flow diagram illustrating steps which may be taken by a device according to the invention pursuant to execution of an interpolation module;

FIGS. 3B–3G are a series of waveform diagrams illustrating operation of a device according to the invention while executing an interpolation module;

FIGS. 3H–3L are diagrams illustrating operation of an interpolation module according to the invention;

FIG. 4A is a flow diagram illustrating steps which may be taken by a device according to the invention pursuant to execution of a high spatial frequency correction module according to the invention;

FIG. 4B is an MTF graph for a particular custom lens;

FIGS. 4C–4K are a series of waveform diagrams and illustrating operation of a verification device according to the invention while executing a high spatial frequency error correction module;

FIG. 5A is a physical form view of a verification system including a hand held verification device interacting with a host processor assembly provided in the specific example by a local area network personal computer;

FIG. 5B shows alternative embodiments of devices which may be employed as a host processor assembly according to the invention;

FIG. 5C is an electro-optical block diagram illustrating an embodiment of an auxiliary reader which may be utilized with a hand held verification device according to the invention;

FIG. 5D is a block diagram corresponding to a host processor assembly according to the invention in one embodiment;

FIG. 5E is an embodiment of the invention wherein a verification system is incorporated in a hand held portable data terminal;

FIG. 5F is an embodiment to the invention wherein a verification system is incorporated into a hand held housing that is especially adapted for use in carrying out print quality measurements;

FIGS. 5G–5L are screen shots illustrating user-interactive GUI display screens which may be displayed on a display during execution of a user-interactive waveform analysis processing module according to the invention;

FIGS. 6A–6D are various assembly views of a device according to the invention;

FIGS. 6E–6J illustrate alternative replaceable alignment windows which may be affixed to a housing of a verification device according to the invention;

FIG. 6K is an exploded assembly view of a verification device according to the invention illustrating assembly thereof;

FIGS. 7A–7D are flow diagrams illustrating operation of a device according to the invention during execution of a print quality measurement module;

FIGS. 8A–8C are integration diagrams illustrating various processing module integration schemes according to the invention;

FIG. 9A is a perspective view of a hand held verification device according to the invention;

FIG. 9B is another perspective view of the hand held verification device shown in FIG. 9A;

FIG. 9C is a top view of the hand held verification device shown in FIG. 9A;

FIG. 9D is a front view of the hand held verification device shown in FIG. 9A;

FIG. 9E is a first side view of the hand held verification device shown in FIG. 9A;

FIG. 9F is a second side view of the hand held verification device shown in FIG. 9A;

FIG. 9G is a bottom view of the hand held verification device shown in FIG. 9A with alignment member deleted;

FIG. 9H is another bottom view of the hand held verification device of FIG. 9A with an alignment member shown and dimensional information (in inches) embedded in the drawing;

FIG. 9I is a tangent line side view of the bar code verification device shown in FIG. 9A with dimensional information (in inches) embedded in the drawing.

DETAILED DESCRIPTION OF THE INVENTION

Perspective views of a bar code verification device **100** according to the invention are shown in FIGS. 1A–1C. Device **100** is configured to be hand held and includes a generally domed shaped housing **1100** having an upper surface **1102**, a first side surface **1104**, and a second side surface **1106**, a front surface **1110** and rear surface **1108**. The diameter of housing **1100** generally decreases from bottom to top. Upper surface **1102**, side surfaces **1104**, front surface **1110**, and rear surface **1108** define upper, side, and rear surfaces of device **100** as shown in FIGS. 1A–1C. Referring to further aspects of housing **1100**, housing **1100** includes a base portion **1114**, which as will be described herein supports an internal support frame **1152** (FIG. 6B) of bar code verification device **100**. Base portion **1114** includes a bottom surface **1116** (FIG. 1C) which defines a bottom surface of device **100**.

Housing **1100** especially adapts device **100** to carry out measurements on bar codes in that housing **1100** shields ambient light which may be provided, e.g., by sunlight or overhead light. Bar codes that are measured and decoded by device **100** are illuminated by LEDs **1082** or other light sources within housing **1100**. By shielding ambient light, housing **1100** assures that consistent illumination conditions are present between measurement and decode sessions of device **100**. Device **100** is configured so that base **1114** is supported on a horizontal surface (e.g., a table top) when device **100** is used to decode a measure print quality of bar codes. More specifically, in use, a substrate, *s*, such as a sheet of paper carrying a bar code to be subject to decoding and print quality measuring is first placed on a horizontal surface. Device **100** is then moved by an operator into such position relative to the substrate, *s*, that housing **1100** covers the bar code symbol, *B*. Specifically, when device **100** is positioned to measure print quality and to decode bar codes opening **1141** (which in the embodiment of FIGS. 6E–6J is defined by a transparent window) of base surface **1116** is positioned over the bar code.

Device **100** further includes a trigger **150**. Trigger **150** in the embodiment of FIGS. 1A–1C is disposed on a top surface of device **100**. Trigger **150** could also be disposed on another surface of device **100**, such as a front surface or rear surface of device **100**. Trigger **150** could also be disposed partially on a pair of adjoining surfaces of housing **1100**. Further, more than one trigger **150** may be disposed on device **100**.

Referring to further aspects of device **100**, the front surface **1110** of housing **1100** includes outer portion **1130** and stepped-in inner portion **1132**. Disposed between outer portion **1130** and inner portion **1132** is window **1134**. Window **1134** could be of a transparent material, thereby preventing foreign objects from entering the inside of the housing. It may be advantageous to have window **1134** include a light attenuating material that will reduce the level of ambient light entering housing **1100**, thereby reducing the false lighting that might otherwise be incident on the bar code under test. The light transmissivity of window **1134** will be properly selected to reduce this interference to acceptable levels. For example neutral density filters, such as the Kodak Wratten filters, might be used. Window **1134** in one embodiment exhibits a transmissivity of about 1%.

There may be other conditions where colored filters might be used, or in some cases combinations of neutral density and color filters might be used. Other filters might be used to attenuate specific spectral components, such IR stop filters. Window 1134 is disposed at an angle so that window 1134 is angled upward from outer portion 1130 to inner portion 1132. Window 1134 could also be disposed substantially horizontally with respect to a horizontal plane. Window 1134 allows bar codes printed on a substrate, *s*, (such as a sheet of paper) to be viewed while device 100 is used to measure print quality of a bar code symbol. It will be seen that housing 1100 and window 1134 may be configured so that window 1134 is removably received thereon. In the view of FIG. 5B (showing device with window 1134 removed), it is seen that window frame 1134*f* defining window aperture 1134*a* can be configured to replaceably receive window 1134. Specifically, frame 1134*f* and window 1134 can be sized so that window 1134 rests within frame 1135 and is further stabilized by the force of gravity. In use, window 1134 might be manually removed from frame 1134*f* during alignment of device 100 relative to bar code, *B*, then, after alignment is achieved, placed back into frame 1134*f* prior to a trigger signal being actuated. Window 1134 may be made opaque to further discourage ambient light rays from reaching bar code, *B*.

For facilitating the centering of a field of view of device 100 on a bar code subject to measuring bottom surface 1116 of device 100 includes an alignment member 1150 comprising alignment formations 1140, 1141, 1142. Alignment formations 1141, 1142, and 1143 can be viewed through window 1134. In use, a user centers device 100 on a bar code symbol such that center alignment formations 1142 are located approximately at a horizontal center of a bar code while outer alignment formations 1141, 1143 are located approximately at edges of a bar code. Forward edge 1146 and rear edge 1145 of opening 1147 are spaced apart such that the spacing between forward straight edge 1146 and rear straight edge 1145 aids in the vertical alignment of device 100 with respect to a bar code symbol to be subject to print quality measurement, also known as symbol verification. In the embodiment shown, forward and rear edges 1146 and 1145 have a spacing of about 0.5 inches. As such, the spacing allows a user to readily confirm that device 100 is vertically centered, e.g., by noting similarly sized gaps between a top of a bar code and forward edge 1146 and a bottom of a bar code and rear edge 1145. Additional aspects of alignment member 1150 and alternative embodiments thereof are described in connection with FIGS. 6E–6J.

Referring to FIGS. 1D–1F, housing 1100 of device 100 in an embodiment of the invention can include a head portion 1135 that defines a lip 1136 extending outwardly from the lateral surfaces (i.e., surfaces 1104, 1108, 1110) of housing 1100. Lip 1136 may be continuously formed about head portion 1135 or else may be discontinuous. Lip 1136 may include surface regions such as region 1138 and region 1139 that are configured to engage an operator's finger and/or thumb when an operator lifts device 100 upwardly. As indicated by the side view of FIG. 1F, Lip 1136 may have portions defining finger or thumb engagement surfaces 1138, 1139 at spaced apart positions about the circumference of head 1135. Where engagement surfaces 1138, 1139 are formed at spaced apart positions, a first engagement surface region 1138 may engage a finger 1141 of an operator as illustrated in FIG. 1D, while a second engagement surface region 1139 engages a thumb 1142 of an operator. Enlarged head portion 1135 greatly enhances the ease with which device 100 can be picked up and moved from position to

position on a substrate, *s*. In the embodiment of FIGS. 1D–1E trigger 150 is positioned in a position that is coordinated with the positioning of lip 1136. It is seen that when device 100 is lifted and moved with utilization of engagement surfaces 1138, 1139, and then subsequently rested on a substrate, *s*, an operator's finger is positioned in such position in close proximity with lip 1136 that it can readily be moved into a trigger actuation position as depicted in FIG. 1E without an operator releasing device 100 from the grasp of the hand including finger 1141. In a further aspect of device 100, housing 1100 defines side grippings formation 1163. Side gripping formations 1163, 1164 are sized to a width such that grippings formations 1163, 1164 are easily grasped by a human hand. Further, the surface of housing 1100 defining gripping formation 1163 is contoured as shown so as to enhance the ease with which gripping formations 1163 may be grasped while reducing the likelihood of an operator's hand slipping while the operator stabilizes device 100 on a substrate. Accordingly, an operator can grip side grasping formation 1163 to stabilize device 100 on a substrate, *s*, during reading.

Dimensional information for device 100 is presented in FIGS. 9H and 9I. The embodiment of FIGS. 9A–9G is dimensioned precisely to the dimension of FIG. 9H and 9I, and the remainder of the embodiments described herein are dimensioned approximately in accordance with the dimensional information provided in FIGS. 9H and 9I. It will be understood that since the depiction of the elements of device 100 are shown in true proportion, the dimensions of any specific feature of device 100 can be determined from the dimensional information presented in FIGS. 9H and 9I although the specific feature dimensions may not be expressly listed. In one specific embodiment of the invention, one or more features of device 100 is scaled by a factor of $\pm 25\%$ relative to the dimensional information of FIGS. 9H and 9I. In another embodiment, one or more features of device 100 is scaled by a factor of $\pm 50\%$. In another embodiment, one or more features of device 100 is scaled by a factor of $\pm 75\%$ relative to the dimensional information of FIGS. 9H and 9I.

A block electro-optical diagram of device 100 is shown in FIG. 2A. Control circuit 1010 includes a central processing unit (CPU) 1005 and memory 1020. CPU 1005 may be disposed on processor IC chip 1030, while memory 1020 may be incorporated partially in IC chip 130 and partially in a plurality of memory IC chips such as EROM IC chip 1022 and RAM IC chip 1021. EROM IC chip 1022 and RAM IC chip 1021 may be in communication with microprocessor IC chip 1005 via system bus 1045. Shown as being provided on an IC processor chip 1030 in communication with a memory 1020, control circuit 1010 can include in place of or in addition to the elements shown additional types of electrical circuits, e.g., analog circuits, and digital logical circuits including programmable logic circuits.

Device 100 also includes an image signal generating system provided by solid state image sensor 1060, available in such technologies as CCD, CMOS, and CID. Solid state image sensor 1060 may be a monochrome or color one-dimensional image sensor or a two-dimensional image sensor. One-dimensional solid state image sensors typically have a single row of photosensitive picture elements or pixels but are available in models having a limited number (e.g., 2) rows of pixels. Two-dimensional solid state image sensors generally have a plurality of photosensitive picture elements or pixels which are formed in a pattern including a plurality of rows and a plurality of columns of pixels. Device 100 further includes an imaging optics 1070 focus-

ing an image onto an active surface of image sensor **1060** and reflector **1075**. Device **100** includes a folded imaging axis **1061** folded by reflector **1075**. Imaging optics **1070** may focus an image of a barcode, B, disposed on a substrate, s, onto image sensor **1060**. The substrate, s, may be e.g., a piece of paper or a film. Target, T, of substrate, s, is the region of substrate, s, corresponding to the field of view of device **100**. Image sensor **1060** may be incorporated on an image sensor IC chip **1066** having disposed thereon image sensor control circuitry, image signal conditioning circuitry, and an analog-to-digital converter. A/D converter **1079** may also be separate from IC chip **1066**. Device **100** may further include a field programmable gate array **1080** (“FPGA”) or the functionality of FPGA **1080** may be incorporated onto processor IC chip **1030**. Operating under the control of control circuit **1010**, FPGA **1080** manages the capture of image data into RAM **1021**. Device **100** further comprises output indicators including red LEDs **1051**, green LEDs **1052** and acoustic output device **1053**. Physical form views of LEDs **1051**, **1052** are shown in FIGS. 1A, 6A and 6C. It is seen that device **100** can have redundant indicators **1051**, **1052**.

A parts list for circuit elements as shown in FIG. 2A, in one embodiment, is presented in Table 1, herein below.

TABLE 1

Circuit Element	Part
Processor IC Chip 1030	Motorola DRAGONBALL MC9328MXL (150 MHZ)
Image Sensor Chip 1060	Toshiba TCD 1305P
Radio 1086	EYSF2CAXX
A/D 1079	National ADC1173 (8 Bit)

Another embodiment is summarized in Table 2 below.

TABLE 2

Circuit Element	Part
Processor IC Chip 1030	Motorola DRAGONBALL MC9328MXL (150 MHZ)
Image Sensor Chip 1060	ICMEDIA, ICM105ATU
Radio 1066	EYSF2CAXX

The circuit of FIG. 2A and the optical elements describe relative thereto may be provided on an OEM image engine of the type available from Hand Held Products, Inc. of Skaneateles Falls, N.Y., such as an 1D IT3800E image/engine or a 2D IT4010/80 image engine.

When control circuit **1010** receives a trigger signal, control circuit **1010** automatically sends appropriate control signals to image sensor chip **1066**. Image sensor chip **1066** in response thereto automatically exposes photosensitive pixels of image sensor **1060** to light and generates image signals. Also in response to receipt of a trigger signal, control circuit **1010** energizes LEDs **1082**, so that substrate, s, is illuminated at least during exposure periods of image sensor **1060**. Light from LEDs **1082** may be shaped by optional shaping optics **1083**. Illumination assembly **1141** comprising LEDs **1082** and optical shaping optics **1083** project an illumination pattern, P, onto substrate, s. LEDs **1082** may be replaced by one or more other light sources such as incandescent lamps, fluorescent lamps, and lasers. The image signals are thereafter automatically converted into digital values by analog-to-digital converter **1079** or by an onboard analog-to-digital converter of image sensor IC chip **1066**. The digital values are received by FPGA **1080** and transferred into RAM **1021**. In accordance with bar code

decoding and print quality measurement programs stored in ROM **1022**, control circuit **1010** attempts to decode a bar code symbol represented in the captured image data performing various measurements to grade the bar code symbol. The capture of image data, decoding, and measurement of print quality by processing of image data occur automatically in response to a trigger signal being received. Control circuit **1010** may be configured to continuously capture image data and process bar code symbols represented therein as long as a trigger signal is received. Device **100** may be configured so that device **100** receives a trigger signal when trigger button **150** is actuated. Device **100** may also be configured to receive a trigger signal when a control button, e.g., button **1668** (FIG. 5A) of a spaced apart device, e.g., of host processor assembly **1210** is actuated.

Imaging assembly **1040**, which in the embodiment described thus far includes an image sensor chip **1066** and imaging optics **1070** may be provided in the form described in connection with FIGS. 2A–2C. Imaging assembly **1040** may also be provided by a laser scan engine, such as an SE1000 scan engine of the type available from Symbol Technologies, Inc. of Holtsville, N.Y.

IC chip **130** may include a plurality of serial I/O interfaces such as general purpose I/O, USB, and Ethernet interfaces and a plurality of parallel interfaces such as CompactFlash and PCMCIA.

Device **100** may further include a plurality of communication links such as a first radio frequency communication transceiver **1082**, a second radio frequency transceiver **1084**, a third radio frequency transceiver **1086**, and an IR communication link **1088** facilitating communication between device **100** and an external device spaced apart from device **100**. As seen in FIG. 2B, device **100** may be part of a local area network (“LAN”) **1200** including a spaced apart and separately housed local host processor assembly **1210** and other portable hand held devices **101-1**, **101-2**, **102**. Gun style hand held device **102** may be provided e.g., by an IT4410 hand held reader, an IT4710 reader, an IT4600 reader, an IT4800 reader or an IT4X80 reader. All of the above readers are manufactured by Hand Held Products, Inc. of Skaneateles Falls, N.Y. LAN **1200** may further include such components as a system backbone **1205**, an access point **1260**, and a server **1250**. As is discussed with reference to FIG. 5D, host processor assembly **1210** may have many components similar to those of device **100**. Host processor assembly **1210** may include a processor IC chip **1230**, a system RAM **1221**, a program memory or system ROM **1222** and a radio frequency transceiver **1282**. Transceiver **1282** may be disposed within housing **1210h** or may be external e.g., tethered to housing **1210h**. By configuring wireless communication between device **100** and host processor assembly **1210** so that a radio frequency transceiver of device **100**, e.g., transceiver **1082** and a radio frequency transceiver of host processor assembly, e.g., transceiver **1282** communicate according to the same communication protocol or standard. In a first embodiment, device **100** and host processor assembly **1210** are configured so that transceivers **1082** and **1282** do not transmit signals of above about 3 milliwatts. Configuring device **100** and host processor assembly **1282** so that transceivers **1082** and **1282** transmit power-limited signals of below about 3 milliwatts reduces the likelihood of interference with other electrical equipment which may be in the vicinity of device **100** and host processor assembly **1282**. Further in accordance with a first embodiment, device **100** and host processor assembly **1282** are configured so that transceivers **1082** and **1282** conduct spread spectrum frequency hopping data transmis-

sions. Configuring device **100** and host processor assembly **1210** to conduct spread spectrum frequency hopping data transmissions further limits the likelihood of radio interference with other radio transmitting electrical devices in the vicinity of device **100** and host processor assembly **1210**. Still further, device **100** and host processor assembly **1210** are configured in accordance with a first embodiment so that when device **100** and host processor assembly **1210** are in communication range of one another, transceiver **1082** and transceiver **1282** automatically communicate with one another to determine whether device **100** is to transmit data to host processor assembly **1210**. The first embodiment may be conveniently realized if transceivers **1082**, **1282** are Bluetooth transceivers appropriately established in accordance with the Bluetooth data transmissions protocol. According to one embodiment of device **100**, radio frequency transceiver **1082** may be a Bluetooth radio frequency transceiver, radio frequency transceiver **1084** may be an 802.11 radio frequency transceiver, while radio frequency transceiver **1086** may be a GSM/GPRS radio frequency transceiver. 802.11 radio frequency transceiver, **1084** generally enables longer range LAN communications than Bluetooth radio frequency transceiver **1082**. GSM/GPRS radio transceiver **1086** enables long range cellular data communications.

Devices **101-1** and **101-2** are "PDT" devices having housing **101h**, while device **102** has housing **102h**. Electrical circuit components and optical components described with reference to FIG. **2A** may be incorporated into housing **101h** and housing **102h**. Devices **100**, **101-1**, **101-2**, **102** are portable such that they are spaced apart from host processor assembly **1210** and may be freely moved by an operator into any desired orientation relative to host processor assembly **1210**. In addition to having wireless communication links, device **100** may include various physical connector interfaces such as an RJ45 connector **1091** associated with Ethernet interface **1090** enabling hard wired communication with host processor **1210**. Device **100** may further be in communication with a plurality of offsite remote host processors **1310** located several miles to thousands of miles away from device **100**. Remote host processors **1310** may be in communication with device **100** via a wide area network **1401**, which may be the Internet. Device **100** may include a browser enabling a user of device **100** to view on display **194** (FIG. **5F**) a web page stored in one of a remote host processor **1310** and to navigate between websites stored on a variety of host processors **1310**. As will be described herein below, device **100** may include connector **1092**, such as a "D Connector" enabling connection of an auxiliary reader unit to device **100**. Signals input to device **100** by an auxiliary reader unit may be processed by comparator **1093** as will be described in connection with FIG. **5A**. Device **100** may communicate directly with network **1400** or indirectly with network **1400** by utilization of network elements of the local area network **1200** including device **100**, and local host processor **1210**. Housing **1100** may encapsulate and support all of the electrical components and all of the optical components shown in the electro-optical diagram of FIG. **2A**.

As indicated by the system diagram of FIG. **5A**, device **100** containing the electrical and optical components of the diagram of FIG. **2A** is in communication with auxiliary reader unit, e.g., unit **1700**. From time to time it may be desirable to capture image data for processing by the circuit of FIG. **2A** with use of image sensing components other than the components contained within device **100**. The system **1400** of FIG. **5A** includes an auxiliary wand reader **1700**.

Wand reader **1700** may have a rugged tip **1702** adapted to contact paper, an imaging lens **1704**, a single element photodetector **1706**, and signal processing circuitry **1708** developing signals output by sensor **1706** into an analog waveform as wand **1700** is dragged across a bar code. Hand reader **1700** may further have a hand held housing **1700h** supporting the above elements. Wand reader **1700** produces image signals when it is physically dragged across a bar code. The image signals produced by wand reader **1700** are smooth waveforms generally regarded to be of higher resolution than those that can be produced by multiple pixel image sensor **1060**. System **1400** may be configured so that wand reader **1700** is detachably attachable to the device **100**. Specifically, a connector of cable **1710** extending from wand reader **1700** may be detachably attached to connector **1092** of device **100** (see FIGS. **1A**, **2A**). Device **100** can be configured so that when wand reader **1700** spaced apart from device **100** is connected to device **100**, signals output by wand reader **1700** are received and processed by device **100**. Specifically, with reference to FIG. **2A**, analog signals output by wand reader **1700** are input into comparator **1093**. Comparator **1093** subjects the input analog waveform to an adaptive threshold test to produce a digital output signal which is input to processor IC chip **1030**. Device **100** then processes the input image signals in accordance with the processing modules described in connection with FIG. **2C**.

Device **100** in one embodiment automatically interrogates connector **1092** to determine whether auxiliary reader **1700** has been connected. If device **100** determines that auxiliary reader **1700** has been connected, device **100** automatically waits for image signals to be received from reader **1700**, and automatically processes the signals when they are received in accordance with processing modules **1402**, **1404**, **1408**, **1410** and **1412**. In one embodiment, auxiliary reader **1700** has substantially the electrical and optical components of FIG. **2A**, but has a housing of a different form factor. For example, auxiliary reader **1700** may have a gun style form factor such as reader **102**. An alternative form factor might be useful, e.g., for reading bar codes in hard to access locations. Auxiliary reader **1700** may also lack one or more of modules **1408**, **1410**, **1412**.

In use, verification device **100** is interactive with and is used in association with host processor assembly **1210**. Host processor assembly **1210** may be provided by e.g. a personal computer as is shown in FIG. **2B**. However, it will be understood that host processor assembly **1210** can be provided by any display-equipped device **100** having suitable processing functionality. As shown in FIG. **5B** host processor **1210** can be provided by an e.g., a PC **1210-1**, a portable laptop computer **1210-2**, a hand held portable data terminal **1210-3**, **1210-5**, or a hand held personal data assistant, PDA **1210-4**. Further, any functionality described herein for local host processor assembly **1210** could readily be accomplished with use of a remote host processor assembly such as any one of the devices labeled assembly **1360** shown in FIG. **2B**.

As indicated previously, a system **1400** that comprises verification device **100** and host processor assembly **1260** can have a plurality of processing modules. A breakdown describing the integration of such processing modules in the various components of system **1400** in one embodiment is described with reference to FIG. **2C**.

In the schematic diagram of FIG. **2C**, verification device **100** includes an image capture module **1402**, a bar code decoding module **1404**, an interpolation module **1406**, a high spatial frequency error correction module **1408**, a bar code print quality measurement module **1410**, and a wave-

form transmittal module **1412**, whereas host processor assembly **1210** includes a waveform receipt module **1420**, user-interactive waveform analysis module **1424** and an auxiliary print quality assessment module **1422**. Image capture module **1402** is generally executed by control circuit **1010** in response to trigger **150** being actuated. The execution of modules **1404**, **1406**, **1408**, **1410**, **1412**, **1420**, and **1422** also follow automatically in response to the actuation of trigger subsequent to the execution of image capture module. The execution of image capture module **1402** generally involves the transmittal of commands from control circuit **1010** to image sensor chip **1066** and the processing of an analog waveform produced by image sensor chip **1066** into digital form with use of an A/D converter. The remaining modules **1404**, **1406**, **1408**, **1410**, **1412**, **1420**, **1422**, and **1424** are conveniently embodied in software (that is, they are performed with use of processor IC chip **1030** or host processor assembly **1210** in response to a program stored in a memory e.g. memory **1021**). However, modules **1404**, **1406**, **1408**, **1410**, **1412**, **1420**, **1422**, and **1424** can comprise hardware circuit components and combinations of hardware and software components. Aspects of the various processing modules are described herein below.

Reference is now made to FIG. 2D showing the flow of execution of processing modules by system **1400** in response to trigger **150** being actuated.

At block **1502**, control circuit **1010** executes processing module **1402** to capture a frame of image data. The frame of image data may be 1D frame of image data or a 2D frame of image data. In one embodiment the frame of image data comprises gray scale pixel values. A 1D frame of image data may comprise an $M \times 1$ array of gray scale pixel values or an $M \times N$ frame of image data where $N \gg M$. e.g., a 2000×2 pixel value frame of image data. A 2D frame of image data may comprise an $M \times N$ frame of image data, where $M, N > 100$. The frame of image data captured at block **150** can also include color-indicating pixel values. The frame of image data captured at block **1502** normally has a number of pixel values equal to the number of pixels of image sensor **1060**. Further, each pixel value in the frame of image data captured by execution of module **1402** normally has an associated position value corresponding to a discrete pixel position of image sensor **1060**. For example, where image sensor **1060** is an image sensor having M column and N rows of pixels, a frame of image data captured at block **1502** may have an $M \times N$ array of pixel values, each having a position value corresponding to a certain pixel of image sensor **1066**, and each pixel value representing light incident at a discrete location on substrate, s . Where image sensor **1060** is an $M \times 1$ image sensor having a single row of pixels, the frame of image data captured at block **1502** may have an $M \times 1$ array of pixel values, each pixel value having a pixel value position corresponding to a pixel of image sensor **1060** and each pixel value representing light incident at a discrete location on substrate, s . It is understood that the capture of a frame of image data at block **1402** that is subject to further processing, control circuit **1010** may capture a plurality of parameter-determining frames of image data for purposes of establishing e.g., exposure parameters.

When executing image capture module **1402** control circuit **1010** may automatically correct image signals generated by image sensor **1060** for fixed pattern noise. Specifically, during execution of module **1402** control circuit **1010** may correct image signals of image sensor **1060** for fixed pattern noise that is attributable to nonuniformities of a projected illumination pattern projected by an illumination assembly **1041** of device **100**. Referring to FIG. 6B, device

100 may include an illumination assembly **1041** including at least one light source such as LEDs **1082** which projects illumination pattern, P , onto substrate, s . However, due to inconsistencies in e.g., the illumination output, degradation level and spacing between each individual LED **1082**, the illumination pattern, P , projected onto substrate, s , will not be completely uniform. FIG. 2F shows a scan reflectance profile for a linear image corresponding to an area of substrate, s , illumination by illumination system **1041**, where substrate, s , is of uniform gray scale. It is seen that because the irradiance level is not uniform, an electronic image corresponding to region of substrate, s , will be affected by fixed pattern noise attributable to radiance non-uniformities of pattern, P .

Accordingly, device **100** may be configured to operate in a calibration mode in which device **100** establishes correction values for signals generated by image sensor **1060**. A calibration mode may be selected, e.g., by decoding with use of device **100** a specially encoded programming bar code symbol, B , which, when recognized by device **100**, causes device **100** to operate in a calibration mode. Device **100** may also be configured so that a calibration mode is commenced when a control button is actuated. The control button may be e.g., a physical button on device **100** or on a device spaced apart from device **100**, e.g. keyboard **1210K** (FIG. 5A). The button may also be a virtual control button displayed on a display of e.g., device **100** or host processor assembly **1210**, as is indicated by calibrate button **2320** shown in FIG. 5L.

When operating in a fixed pattern noise calibration mode, control circuit **1010** may operate in accordance with the flow diagram of FIG. 2G. At block **2302** control circuit **1010** captures a test frame of image data. Typically at block **2302** control circuit **1010** captures an image representation of a uniform gray scale substrate, s , such as a white sheet of paper. Illumination assembly **1041** is controlled to be energized while the test frame is captured at block **2302** in such manner that the image data represents the radiance nonuniformities of pattern, P . At block **2304** control circuit **1010** determines correction values for correcting image signals of image sensor **1060**. In one embodiment, control circuit **1010** at block **2304** calculates correction pixel values for each pixel position of the test frame captured at block **2302**. The correction pixel values determined at block **2304** are determined such that when scaled by its corresponding calculated correction pixel value, each pixel position of the corrected image has an equal gray scale value. At block **2306** control circuit **1010** stores the determined pixel correction values into a nonvolatile memory device such as EROM **1022**. By storing the values into a nonvolatile memory device **1022** the correction values are retained after device **100** is powered down. It will be seen that the calculated correction values will correct for fixed pattern noise attributable to sources other than illumination assembly **1041**, e.g. lens **1070** and image sensor **1060**.

Device **100** may include hardware elements that appropriately boost or reduce the amplitude of image signals output from image sensor **1060** in accordance with correction values determined at block **2304**. Alternatively, control circuit **1010** may correct image data in accordance with stored fixed pattern noise correction values by scaling pixel values of a preliminary memory-stored frame of image data in accordance with stored pixel correction values after the preliminary frame of image data is stored into RAM **1021**.

It may be desirable to operate device **100** in accordance with the calibration mode several times during the lifetime of device **100**. Device **100** may require fixed pattern noise

calibration, for example, if some of LEDs **1082** become degraded due to age, or if one or more of LEDs **1082** becomes nonfunctional.

At block **1504**, control circuit **1010** executes decoding module **1404** to attempt to decode a bar code. Information respecting various reference bar code decoding routines is available from the Association for Automatic Identification and Mobility (“AIM”), at www.aimglobal.org. Information respecting various bar code decoding routines is also available in various standards published by the International Standards Organization (“ISO”). When device **100** successfully decodes a bar code, device **100** stores a decoded out message at a memory location of device **100**. If at block **1505** device **100** determines that bar code decoding is not successful, device **100** outputs an error message at block **1507** (such as a read failure message to display **1210d** of host processor assembly **1210** or display **194** of device) and waits for a next trigger actuation. Alternatively, after attempting to decode a bar code symbol at block **1504**, control circuit **1010** may proceed directly to block **1506** whether or not a decode attempt at block **1504** is successful. Device **100** may be configured so that device **100** actuates green LEDs **1052** if decoding is successful at block **1504**. Device may also be configured so that device **100** actuates red LEDs **1051** if decoded at block **1505** is not successful. Device may also be configured to actuate acoustic output **1053** if decoding is successful. Referring to FIG. 6A, an operator can observe light from LEDs **1051** and **1052** by viewing through window **11354** into an interior of housing **1100**.

At block **1506** control circuit **1010** executes interpolation module **1406**. By execution of interpolation module **1406** control circuit **1010** determines constructed pixel values for interpolated pixel positions intermediate “actual” pixel positions of a frame of image data. Control circuit **1010** can interpolate one or more constructed pixel values between each “actual” pixel value that corresponds to a position of an individual pixel of image sensor **1060**. In one embodiment, control circuit **1010** interpolates constructed pixel values from actual pixel values by way of a process of linear interpolation. In executing a linear “straight line” interpolation process relative to a linear gray scale image, control circuit **1010** may determine that a constructed pixel position intermediate adjacent actual pixel positions having gray scale values of 50 gray scale and 100 gray scale, should have a value of 75 gray scale. FIG. 3I shows a representation of a reference reflectance profile **6013** representing the image on substrate, *s*, which is sampled at pixel positions P_{N-2} through P_{N+3} . In a particular example, control circuit **1010** may process the gray scale linear frame of image data represented in FIG. 3K, wherein P_{N-1} , P_N , P_{N+1} represent original pixel value positions of an input one dimensional frame of image data, each corresponding to an individual pixel of image sensor **1060**, and wherein the pixel positions have the gray scale pixel values (. . . , 70, 50, 100 . . .) indicated. In executing interpolating interpolation module **1406**, control circuit **1010** produces the enhanced resolution gray scale frame of image data indicated by FIG. 3L. The frame of image data represented by FIG. 3I includes having gray scale pixel values calculated by way of linear interpolation for interpolated pixel positions, *I*, intermediate actual pixel positions. In executing module **1406**, control circuit **1010** develops an electronic representation of a bar code symbol that more accurately represents the characteristics of the printed bar code symbol printed on substrate, *s*, than the originally captured image captured at block **1502**.

Constructed pixel values for interpolated pixel positions intermediate of original pixel positions (e.g., “actual” pixel positions having values corresponding to light on an individual pixel of sensor **1060**) can also be calculated with utilization of a non-linear interpolation process. An example of the invention wherein control circuit **1010** utilizes a sinc function to calculate constructed pixel values at interpolated pixel positions intermediate actual pixel position is described with reference to FIG. 3A. At block **6004**, control circuit **1010** calculates sinc functions at each sample position (e.g., for each pixel position having a pixel value). The result of processing block **6004** is described with reference to the waveforms diagrams of FIGS. 3H, 3I, and 3J. The sinc function given by the formula $\text{sinc}(x) = \sin(x)/x$ at any given sample position has the characteristics represented by waveform **6012** (FIG. 3H). Superimposed sinc function waveforms for several sample positions are shown in FIG. 3J. At block **6006**, control circuit **1010** sums the sinc function at each sample position and each desired interpolated position. The resulting smoothed waveform **6014** (FIG. 3J) represents the result of interpolating sample values at a very large number of interpolated positions. It will be seen that processing speed can be increased by calculating constructed sample (e.g. pixel) values for fewer numbers of interpolated sample positions. Processing speed can also be increased by establishing windowing parameters that modify each sinc function so that each determined sinc function contributes to the calculated value of a fewer number of interpolated sample positions. Referring to the flow diagram of FIG. 3A, control circuit **1010** at block **6002** may establish windowing parameters and at block **6004**, control circuit **1010** may calculate sinc functions utilizing the windowing parameters established at block **6002**. With reference to FIG. 3J, it is seen that without establishing windowing parameters, a sinc function for each sample position would produce a value contributing to the calculated constructed sample value at each interpolated sample position. That is, in an initial sample having 1024 pixel values corresponding to a row of pixels and where it is desired to calculate a single interpolated pixel value intermediate each original pixel value, control circuit **1010** would sum 1024 sinc function values for each interpolated pixel position.

Referring again to the flow diagram of FIG. 3A control circuit **1010** at block **6002** may establish simple threshold windowing parameters which discard sinc function values below a predetermined value. Sinc function values may also be discarded with use of a peak limiting function which discards a predetermined number of peaks of a sinc function waveform. Control circuit **1010** may also at block **6002** modify a sinc function utilizing an exponential function. With utilization of an exponential function, windowing parameters can be established which substantially reduce the time required for calculation of a constructed sample value without substantial reduction of information contained in an original set of sinc function waveforms. Further aspects of an embodiment of interpolation module **1406** are described in connection with Example 1 herein below. In Example 1, a transfer function executed by control circuit **1010** when executing interpolation module **1406** includes a sinc function and an exponential function, the exponential function reducing the number of interpolated sample positions for which the sinc function for a given sample position contributes a value.

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EXAMPLE 1

An under sampled signal is processed. The initial bar code data prior to sampling is represented in the waveform diagram of FIG. 3B. The waveform of FIG. 3B is then sampled with sample spacing of Period2. The waveform diagram presented in FIG. 3B is a scan reflectance profile in which image data sample values are expressed in terms of ratio to maximum values. In the present example, a larger number corresponds to a higher reflectance, i.e., white is high. The sampled bar code data is shown in FIG. 3C with each sample point noted.

A sinc function is given by eq. 1-1 below, wherein a functional definition of the sinc function is conditional to avoid the singularity at 0.

$$\text{sinc}(x) := \text{if} \left[(x) = 0, 1, \frac{\sin(\pi \cdot x)}{\pi \cdot x} \right] \quad (\text{eq. 1-1})$$

A waveform diagram wherein values generated in accordance with the sinc function given by eq. 1-1 is presented in FIG. 3D. It is seen from the waveform diagram of FIG. 3D that the transfer function given by eq. 1-1 exhibits a decay such that hundreds of terms in a series expansion might be needed in order to converge with reasonable precision. FIG. 3E is a waveform diagram representing a sinc function modified utilizing an exponential function windowing parameter. The transfer function represented by the waveform diagram of FIG. 3E includes a sinc function term multiplied by an exponential decay term. Sinc function terms (modified by the exponential decay function) below predetermined amplitudes can be discarded without significant loss of signal reconstruction accuracy. Modified sinc function terms modified with an exponential damping function can be discarded by way of subjecting the modified sinc function to a simple threshold procedure to eliminate values below a predetermined near-zero value. The summation in Example 1 is truncated after about 60 terms. It is seen that the processing speed can be increased by establishing an appropriate windowing parameter.

The 6 mil (1 mil=1/1000 inch) narrow element width sampled bar code data presented by the waveform diagram of FIG. 3C is at 5 mil intervals.

Constructed sample values are calculated from sample data presented in FIG. 3C utilizing a series of sinc functions. Sampling spacing of interpolated sample values is set to 1 mil per sample. A sinc function argument is given by eq. 1-2 through eq. 1-4 as follows:

$$\text{Period2} = 5.0 \text{ mils} \quad (\text{eq. 1-2})$$

$$fs := \frac{1}{\text{Period2}} \quad (\text{eq. 1-3})$$

$$\omega c := 2 \cdot \pi \cdot \frac{fs}{2} \quad (\text{eq. 1-4})$$

Where ωc , the frequency of the sinc function argument, is given by $\omega c=0.628$. An exponential windowing function is established as follows:

$$a = 5 \quad (\text{eq. 1-5})$$

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-continued

$$Ex(k) := 8^{-\left(\frac{k}{a}\right)^2} \quad (\text{eq. 1-6})$$

Where a is the exponential damping factor. A series expansion, where sum is the extent of the summation, for use in reconstructing the waveform values at the interpolated sample positions with separation DataSep:=1 is as follows:

$$xr(t) := \sum_{n=\text{floor}\left(\frac{t-\frac{\text{sum}}{2}}{\text{Period2}}\right)}^{\text{floor}\left(\frac{t+\frac{\text{sum}}{2}}{\text{Period2}}\right)} BS(n \cdot \text{DataSep}) \cdot \text{Period2} \cdot \frac{\omega c}{\pi} \cdot \text{sinc} \left[\omega c \cdot \frac{(t - n \cdot \text{Period2})}{\pi} \right] \cdot Ex \left[\omega c \cdot \frac{(t - n \cdot \text{Period2})}{\pi} \right] \quad (\text{eq. 1-7})$$

In accordance with the transfer function of eq. 1-7 a waveform will be reconstructed with samples at 1 mil intervals. Segments of the output waveform resulting from subjecting the input waveform of FIG. 3C to the transfer function of eq. 1-7, where period2=5.0 mils, a=2.5 mils and sum=60 are presented in FIGS. 3F and 3G. FIG. 3F illustrates the interpolated or reconstructed waveform from sample numbers 0-450 while FIG. 3G illustrates the interpolated waveform from sample numbers 0-145.

Accordingly, it is seen that a bandwidth limited signal that is sampled can be reconstructed with improved precision using an appropriately dimensioned series of sinc functions. An exponential window parameter or function can significantly reduce the number of terms in the series without significantly impacting the accuracy of the reconstructed waveform.

END OF EXAMPLE 1

At block 1508 control circuit 1010 executes high spatial frequency error correction module 1408. Device 100 may include a lens 1070 that has an approximately linear modulation transfer function (MTF) fall off with spatial frequency. Accordingly, device 100 may exhibit reduced optical resolution and edge contrast at higher spatial frequencies. In order to correct for reduced optical resolution at higher frequencies, a frame of image data may be subject to the processing that is described with reference to the flow diagram of FIG. 4a. At block 8002 control circuit 1010 determines the Fourier transform of an input linear gray scale pixel image (e.g., an Mx1) array of pixel values. The image data input at block 8002 may be the enhanced resolution image data output by control circuit 1010 when executing interpolation module 1406, or may be the image data captured by control circuit 1010 pursuant to execution of image capture module 1402, if for example interpolation module 1404 is not executed or not executed prior to execution of module 1408. Determining the Fourier transform of a gray scale pixel image expresses the original space-domain image information in the frequency domain. At block 8004 control circuit 1010 subjects the Fourier transform determined at block 8002 to an adjustment process which may comprise a vector multiplication function. For example, at block 8004 control circuit 1010 may multiply the Fourier transform determined at block 8002 in accordance with an appropriately defined straight line gain

as a function of frequency as is explained with reference to Example 2. Subjecting at block 8004 the Fourier transform determined at block 8002 to an appropriate multiplication function increases the amplitude of the Fourier transform at certain frequency components without substantially affecting the amplitude of the Fourier transform at other frequency components. Control circuit 1010 at block 8006 converts the adjusted Fourier transform to the space domain by determining the inverse of the adjusted Fourier transform that has been adjusted at block 8004. In executing module 1408 control circuit 1010 develops an electronic representation of a bar code symbol that more accurately represents the characteristics of the printed bar code symbol printed on substrate, s, than the originally captured image captured at block 1502. Although the implementation shown relies upon the use of the Fourier transform, alternate transforms might also be utilized, such as sine, cosine, wavelet or Laplace transforms.

Those skilled in the art will recognize that enhancement of the higher spatial frequencies, as implemented in module 1408 by control circuit 1010, could also be accomplished using a number of alternate techniques, many of which would not require the use of Fourier transform techniques. Examples are properly defined and dimensioned FIR (Finite Impulse Response) and IIR (Infinite Impulse Response) filters, both of which would be implemented by the control circuit 1010 or in a separate digital processing element (not shown in the drawings) or even by more traditional analogue electronic high pass filters that might be implemented in the analog domain after imager 1060 and prior to the A/D converter 1079 shown in FIG. 2a.

EXAMPLE 2

An imaging lens 1070 of device 100 in an embodiment subject to analysis exhibits an approximately linear MTF fall off with spatial frequency. This MTF profile for a custom singlet such as might be used in this product is shown in FIG. 4B. This profile was created using the optics design program ZEMAX from the ZEMAX Development Corporation. The approximately linear MTF fall off of the lens results in reduced optical resolution and edge contrast at the higher spatial frequencies. The present custom lens has an MTF of approximately 71% at 20 cycles per mm in imager space. This optical pattern is imaged on a one dimensional CCD image sensor converting the optical representation of the bar code pattern under test to an electrical waveform. In an analogous fashion, the electrical signal exhibits an approximately linear fall off with frequency in the electrical domain.

An EAN128 999999/R1 symbol is sampled by capturing a 1D frame of image data. The file length of the input signal is 3,646 elements (gray scale pixel values) long. The original EAN bar code signal is represented in the center portion of FIG. 4C. FIG. 4C shows a scan reflectance profile of an EAN bar code symbol with an average narrow element width of 6.6 mils. At each end of the field of view 1.8 LP/mm test targets can be seen. It is observed from the scan reference profile of FIG. 4C that increased signal results in a lower count, i.e., white is low.

A portion of the sampled data is shown in FIG. 4D with the actual sample points marked. It is observed that the data is adequately sampled at about 4 samples per narrow element.

The result of determining the Fourier transform of the original bar code signal is presented in the waveform diagrams of FIGS. 4E and FIG. 4F. FIG. 4E illustrates J

index frequency components from 0 to 3500, while FIG. 4F illustrates J index frequency components from 0 to 1000. In this example A represents the scan reflectance profile as shown in FIG. 4C and B is the Fourier transform of A. Thus, $B:=\text{cfft}(A)$.

The Fourier transform of the original input image includes a real and imaginary component. The original file contains 3645 data points and, as a result, the transform file contains 1822 complex elements. Further, the magnitude of the Fourier transform image data is symmetric about the point 1823. Each CCD pixel has a width of 8 um and the system optical magnification is 5x. Thus, in paper space each pixel spans a width of:

$$\text{Pix}=0.008 \text{ mm} \tag{eq. 2-1}$$

$$\text{PixPaper}=\text{Pix} \cdot 5 \tag{eq. 2-2}$$

$$\text{PixPaper}=1.575 \times 10^{-3} \text{ in. or } 1.6 \text{ mils} \tag{eq. 2-3}$$

Accordingly, $\text{Scan Width}=\text{PixPaper} \cdot 0.3645=5.74 \text{ in.}$ The frequency span per count, and the full scan frequency span, are given by eq. 2-4 and eq. 2-5 respectively.

$$\frac{1}{\text{ScanWidth}} = 6.859 \times 10^{-3} \frac{1}{\text{mm}} \tag{eq. 2-4}$$

$$\frac{1}{\text{ScanWidth}} \cdot 1822 = 12.497 \frac{1}{\text{mm}} \tag{eq. 2-5}$$

Thus, the largest complete sine cycle that can be scanned would span 5.74 inches in paper space. This corresponding to the lowest detectable frequency in paper space. Thus, in paper space, a single count corresponds to a spatial frequency of 6.859×10^{-3} cycles/mm. The full scale span in paper space would therefore be 1822 times this value, or 12.50 cycles per mm.

In this example, the highest spatial frequency of importance in paper space is 4.0 LP/mm (corresponding to a minimum bar code element size of 5.0 mils). Because the optical system has a 5x magnification, this corresponds to a spatial frequency of 20 LP/mm at the image sensor. The lens MTF as seen in FIG. 4B has an MTF of approximately 71% at 20 LP/mm.

From the calculations above, the spatial frequency count associated with 4 LP/mm can be found by dividing 4.0 by the spatial frequency of 6.859×10^{-3} cycles/mm.

$$\text{Count} = \frac{4}{6.859 \cdot 10^{-3}} \tag{eq. 2-6}$$

$$\text{Count} = 583$$

ZEMAX optical modeling software was used to model the optical system of device 100. From the ZEMAX analysis of the optical system, it was observed that 20 cycles per mm in imager space corresponds to 4 cycles per mm in paper space. Also, at this point frequency, the MTF is approximately 0.71. From the calculations above, 4 cycles per mm exhibits an index of 583. To compensate for the reduced MTF of the lens, the gain might be set to $1/0.71=1.41$. As an initial value, use a compensation gain g. of 1.00.

A gain function was established as a linear function of frequency. Gain was established to be symmetrical about the point 1822. The gain function, where $g=1.0$, is expressed by eq. 2-7.

$g = 1.0$ (eq. 2-7)

$$G_j = \text{if} \left[j \leq 1822, \left(1 + g \cdot \frac{j}{1822} \right), \left(1 + \frac{3644 \cdot g - j \cdot g}{1822} \right) \right]$$

Eq. 2-7 is shown graphically in FIG. 4G. Utilizing the frequency dependent gain function of eq. 2-7, the Fourier transform shown graphically in FIGS. 4E and 4F is adjusted. This is accomplished by multiplying each complex term of the Fourier transformed input signal by each term of the frequency dependent gain term G_j .

$$C_j = G_j \cdot B_j \quad (\text{eq. 2-8})$$

The inverse of the adjusted Fourier transform is then determined as represented by the term D below:

$$D = \text{icfft}(C) \quad (\text{eq. 2-9})$$

FIGS. 4H–4K illustrate representations of the corrected frame of image data. FIG. 4H illustrates the result of the correction over all pixel positions. FIGS. 4I and 4J illustrate the result of the correction over select ranges of pixel positions. FIG. 4I illustrates the original signal and the signal after high frequency correction. FIG. 4J shows the two waveforms superimposed on one another in order to show the improvement in the high frequency spatial components. The original waveform is shown as the solid line and the improved waveform is the dashed line. FIG. 4K shows the 1.8 LP/mm test target at the extreme left of the field of view. Observe in both FIG. 4J and FIG. 4K that there is a noticeable improvement in the signals associated with the high frequency components without any noticeable distortion degradation visible on the wide bar elements.

The results presented suggested that at least the 6 mil waveform tested can be digitally corrected to compensate for the optical MTF reduction caused by imaging lens 1070. The gain used to implement this correction is approximately that required to compensate for the lens MTF role off at 4 LP/mm in paper space.

END OF EXAMPLE 2

While the flow diagram of FIG. 2D illustrates that control circuit 1010 decodes a captured frame of image data in accordance with module 1404 prior to executing interpolation module 1406 and high spatial frequency correction module 1408, control circuit 1010 may execute decode module 1404, automatically in response to receipt of a trigger signal subsequent to execution of interpolation module 1406 and subsequent to the execution of high spatial frequency error correction module 1408 so that enhances image data is processed during decoding. If control circuit 1010 executes the image enhancement interpolation module 1406 and the image enhancement high spatial frequency error correction module 1408 the success rate of the execution of decode module 1404 can be expected to be improved. It will be understood that while modules 1406, 1408 enhance the quality of a captured image, control circuit 1010 may execute only one of modules 1406, 1408 or neither of modules 1406, 1408. Processing modules 1406, 1408 have been described relative to processing of linear image data. Control circuit 1010 may also input 2D image data while executing modules 1406, 1408. Where control circuit 1010 processes linear image data, input image data may be image data representing e.g., light incident on a row of pixels of a one dimensional image sensor, a row of pixels of a 2D image

sensor, light incident on a selected row of pixels of a 2D image sensor, or light incident on a transverse line of pixels of a 2D image sensor, such as a diagonal or other transverse straight or curvilinear line of pixels. The input image data input for processing pursuant to the execution of module 1406, 1408 normally comprises pixel data including a plurality of pixel values, each pixel value corresponding to a specific pixel position, wherein each pixel position represents light incident a specific location of target T.

At block 1510 control circuit 1010 executes print quality measurement module 1410 to carry out a series of measurements on the frame of image data that has been processed by interpolation module 1406 and high spatial frequency error correction module 1408 or an unprocessed frame of image data captured at block 1502 if modules 1406, 1408 are deleted. Referring to the flow diagram of FIG. 7A, measurements on the input frame of image data that may be conducted during the execution of block 1510 may include a symbol contrast measurement (block 4102), an edge contrast minimum measurement (block 4110), and modulation measurement (block 4120). Information respecting the above measurement is described in detail in the previously referenced ANSI (X3.182-1990) and ISO (ISO/IEC 15416 and ISO/IEC 15415) Standards (the “ISO/IEC bar code verification specification standards”). In addition to carrying out symbol contrast, edge contrast and, modulation measurements while executing processing module 1410, control circuit 1010 may carry out additional measurements that are in accordance with the above referenced ISO/IEC bar code verification specification standards. With further reference to the execution of processing module 1410 in executing block 4102, and with particular reference to the flow diagram of FIG. 7B control circuit 1010 at block 4103 finds the highest peak of an input scan reflectance waveform. If the input waveform is the corrected waveform 4150 of FIG. 4J the highest peak may be determined to be peak 4150. At block 4105 control circuit 1010 determines the lowest peak of an input scan reflectance waveform, which may be low peak 4153 if the input waveform is the corrected waveform of FIG. 4J. At block 4107 control circuit 1010 calculates the difference between the peak value of the peak identified at block 4103 and the peak value of the peak identified at block 4105. At block 4109 control circuit 1010 stores the calculated symbol contrast measurement calculated at block 4107 into a memory device such as device 1021. Amplitudes of waveform 4150 of FIG. 4 can be expressed in reflectance units (typically a percent of 100% reflectance) by application of a calibration step in which the amplitudes are calibrated with reference to reflectance calibration standards (e.g., one light and one dark).

Referring to the flow diagram of FIG. 7C a method for measuring edge contrast is described. At block 4111 control circuit 1010 identifies the worst pair of peaks. Each pair of peak e.g., peak 4155 and peak 4157 of a scan reflectance waveform represents an edge of a bar code symbol. The worst pair of peaks is the pair of peaks having the smallest reflectance difference. The identified worst pair of peaks may represent either a transition from a space to a bar or a transition from a bar to a space. Thus, at block 4111, where the corrected waveform 4150 of FIG. 4J is the input waveform, control circuit 1010 may identify peaks 4159 and peak 4161 as the worst pair of peaks. At block 4113 control circuit 1010 identifies the reflectance difference between the high peak 4159 and the low peak 4161 of the worst pair of peaks identified at block 4111. At block 4115 control circuit 1010 stores the minimum edge contrast value determined at block 4113 into a memory device 100, e.g., RAM 1021.

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Referring to the flow of diagram of FIG. 7D a method for measuring symbol modulation is described. Modulation is a measurement of the capability of a narrow element of a symbol to be recognized as compared to wide symbol element. At block 4121, control circuit 1010 retrieves the symbol contrast measurement from a memory device 100 that was stored into memory at block 4109. At block 4123 control circuit 1010 retrieves from memory e.g., memory 1021 the minimum edge contrast measurement that was stored into memory at block 4115. At block 4125 control circuit 1010 applies the retrieved values to the formula $\text{Modulation} = \text{EC}_{\text{MIN}} / \text{SC}$, where EC_{MIN} is the minimum edge contrast measurement determined at block 4113 and SC is the symbol contrast measurement determined at block 4107. At block 4127 control circuit 1010 stores the resulting modulation measurement into a memory device 100 of system 1400, e.g., memory 1021.

At block 1512 control circuit 1010 executes waveform transmittal module 1412. Specifically at block 1512 control circuit 1010 sends image data such as the processed frame of image data processed by modules 1406, 1408 and/or the captured frame of image data captured by execution of module 1402 to separately housed and spaced apart host processor assembly 1210. Also at block 1512 control circuit 1010 sends measurement data resulting from execution of processing module 1410 to host processor assembly 1210. Host processor assembly 1210 then receives the transmitted frame of image data and the measurement data at block 1520 by execution of waveform receive module 1420. As eluded to in connection with FIG. 2A, verification device 100 in executing module 1412 may transmit the waveform wirelessly over a wireless communication link 1500 as is indicated in FIG. 2C.

For determining whether executing waveform transmission module 1412 is appropriate, control circuit 1010 may operate in accordance with the flow diagram of FIG. 2E. At block 2202 control circuit 1010 receives a trigger signal as may be actuated remotely or by actuation of trigger 150 to commence a first decode and measurement session. At block 2204 control circuit 1010 polls data communication components of device such as transceiver 1082 to determine whether device 100 is presently able to send data to a desired destination, e.g. host processor assembly 1210. At block 2206 control circuit 1010 determines whether data communications are currently impeded. Data communication may be impeded, e.g. if device is out of range with respect to a desired data receipt device, e.g. host processor assembly 1210. If data communications are determined to be presently impeded, control circuit 1010 proceeds to block 2208. At block 2208 control circuit 1010 executes processing modules 1402, 1404, 1406, 1408, and 1410 but does not execute waveform transmittal module 1412 to transmit measurement and other data to host processor assembly 1210. Instead, control circuit 1010 proceeds to block 2210 to archive measurement data determined at block 1510, decoded out data message data determined at block 1504 (not mentioned in the FIG. 2E flow diagram) and image data memory, e.g. memory 1021. In archiving data at block 2210, control circuit 1010 stores data in such manner that it can be later uploaded to host processor assembly 1210. Thus, at block 2210 control circuit 1010 may store measurement data, message data, and image data in memory locations other than temporary (sometimes referred to a buffer) memory locations that are continuously written over each time a trigger signal is received. When control circuit 1010 has completed block 2210 control circuit 1010 returns to block

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2202 to wait for another decode and measurement session to be commenced by a receipt of a trigger signal.

Referring again to block 2206, if at block 2206 control circuit 1010 determines that data communications between device 100 and host processor assembly 1210 are not impeded, control circuit 1010 proceeds to block 2212. At block 2212, control circuit 1010 executes processing blocks 1402, 1404, 1406, 1408, and 1410. In the execution of block 2212, control circuit 1010 may store data such as image data and measurement data (e.g. symbol contrast, edge contrast, and modulation measurement data) and decoded out message data into buffer memory locations of memory device 1021 for purposes of facilitating an immediate transmission of the data to host processor assembly 1210. However, since host communications are determined to be available, there is no need for control circuit 1010 at block 2212 to archive data into a memory of device 100 in such form that it is available for transmission after a future decode and measurement session. With further reference to the flow diagram of FIG. 2E control circuit 1010 at block 2214 transmits measurement data, decoded message data, and image data of the current decode and measurement session to host processor assembly 1210. The image data referred to in blocks 2210, 2214, and 2216 may be the captured image data captured by execution of module 1402 and/or the processed image data processed in accordance with one or more of modules 1406, 1408. Then at block 2216 control circuit 1010 transmits archived measurement, decoded message data, and image data from previous decode and measurement sessions. Device 100 may be configured so that at block 2216 control circuit 1010 uploads to host processor 1210 all archived measurement, decoded message data, and image data that has been archived by device 100 during each preceding decode and measurement session since the time communications were determined to be impeded. Device 100 can also be configured so that at block 2216 device 100 uploads data from 1 to N previous decode and measurement sessions. Device 100 can be configured so that when archived data is transmitted at block 2216 archive data memory locations of a memory device such as memory 1021 for archiving data pursuant to block 2210 are emptied (e.g. written over with void data). Accordingly, if communications were determined to be unimpeded at block 2206 during an immediately preceding decode and measurement session, control circuit 1010 at block 2216 may after determining that void data is present avoid transmitting archived measurement data, decoded message data, and image data at block 2216 and proceed immediately to block 2202 to wait for a next decode and measurement session to be commenced, by the actuation of a trigger signal.

At block 1522, host processor assembly 1210 executes auxiliary print quality measurement module 1422. In executing auxiliary print quality measurement module 1422 host processor assembly 1210 carries out measurements on the frame of image data transmitted at block 1512 in addition to those measurements performed by control circuit 1010 of verification device 100 pursuant to execution of print quality measurement module 1410. In one example of the invention, device 100 at block 1510 performs a subset of bar code print quality measurements described in the ISO/IEC Bar Code Verification Standards, and at block 1522 host processor assembly 1210 performs additional bar code print quality measurements described in the ISO/IEC Bar Code Verification Standards.

At block 1524, host processor assembly 1210 executes user-interactive waveform analysis module 1424. In executing user interactive waveform assessment module 1424 host

processor assembly **1210** causes a graphical representation corresponding to the waveform or image frame transmitted at block **1512** to appear on display **1210d** of host processor assembly **1210**. The graphical display of image data typically comprises a scan reflectance profile, which is a graphical representation readily determined from a gray scale image map. When gray scale pixel values corresponding to positionally adjacent pixel positions are plotted in graph, the graph (when representing a bar code) has a generally sinusoidal waveform, and is known as a scan reflectance profile. The graphical display by host processor assembly **1210** of a scan reflectance profile by host processor assembly **1210** provides significant advantages. In certain instances, characteristics of a printed bar code symbol can readily be determined by observation of a displayed scan reflectance profile that cannot easily be determined by observation of numerical measurement values. In addition to displaying a graphical representation of the transmitted image, host processor assembly **1210** by execution of module **1424** may, with use of a graphical user interface (GUI), make a variety of user selectable options available for selection by a user. Such option may include, for example, display of the result of the measurements made by verification device **100** during execution of module **1410**, and display of the result of the measurements made by host processor assembly **1210** during execution of module **1422**.

A physical form view of the system **1400** schematically depicted in FIG. **2C** is shown in FIG. **5A**. In the embodiment of FIG. **5A** host processor assembly **1210** is provided by a desk top personal computer PC **1210-1** having a graphical user interface (GUI). The graphical user interface includes a pointer **1652** which is manipulated into a variety of positions of display **1210d** by an operator. While the pointer controller of host processor assembly **1210** in the embodiment shown includes a mouse **1654** for moving pointer **1652**, another type of pointer controller (e.g. a trackball, a navigation matrix) may be used. A user moves pointer **1652** between various icons **1662**, **1664**, **1666** corresponding to various control options. Keyboard **1210k** may also be utilized to move pointer **1652**.

In the example of FIG. **5A**, host processor assembly **1210** operates in a mode in which host processor assembly **1210** displays on display **1210d** a scan reflectance profile **1670**, enabling an operator to view a graphical waveform representation of input image data. The mode of operation depicted in FIG. **5A** had previously been entered into by the selection of a scan reflectance profile control button **1666** labels "SRP." With reference to FIG. **5G**, another mode of operation of host processor assembly **1210** is depicted. As shown in FIG. **5G**, host processor assembly **1210** displays on display **1210d** various bar code pint quality measurement data. The mode of operation depicted in FIG. **5G** is entered into by selection of control button **1662**. In the mode of operation depicted in FIG. **5G**, host processor assembly displays symbol contrast measurement data, as calculated at block **4107**, edge contrast data **1672** as calculated at block **4113** and modulation data **1673** as calculated at block **4125**. While the modes of operation in which host processor assembly **1210** displays on display **1210d** a scan reflectance profile **1670** and the mode in which host processor assembly **1210** displays measurement data are depicted as occurring sequentially in response to user input, they can also occur simultaneously. For example in the embodiment of FIG. **5L**, host processor assembly **1210** simultaneously displays a scan reflectance profile **1670** and edge contrast measurement data **1672**. Host processor assembly **1210** also may have a

mode of operation in which decoded bar code data **1674**, as shown in FIGS. **5A** and FIGS. **5G-5J** decoded at block **1404** is displayed.

Reference is now made to FIG. **5e**, in which another embodiment of the invention is shown. The portable data terminal of FIG. **5E** has the processing module integration scheme as depicted in FIG. **8A**. Portable data terminal **101** has processing modules **1402**, **1404**, **1406**, **1408**, **1410**, **1422** and **1424** integrated therein. As indicated previously, an imaging assembly **1040** as well as the other components described in connection with FIG. **2A** may be incorporated within hand held portable data terminal **101** and may be encapsulated by housing **101h**. Processing modules **1402**, **1404**, **1406**, **1408**, **1410**, **1422** and **1424** in the embodiment of FIG. **5E** are contained within hand held housing **101h**. Incorporating all of processing modules **1402**, **1404**, **1406**, **1408**, **1410**, **1422** and **1424** within a single hand held unit provides certain advantages. In the embodiment of FIG. **5E**, waveform transmittal modules **1412** and receipt module **1420** are not needed. Accordingly, the embodiment of FIG. **5E** does not require data communications circuitry for communicating data between spaced apart devices. Referring to further aspects of portable data terminal **101**, portable data terminal **101** includes a keyboard **101k** a trigger button **150** and a pointer controller shown as being provided by a navigation matrix **1655**. In execution of user-interactive waveform analysis module **1424**, portable data terminal **101** may display on display **101d** any one of the display formats depicted in FIGS. **5G-5L**. Because the screen formats of FIGS. **5G-5L** may be displayed by host processor **1210** or by portable data terminal **101** configured in accordance with the integration scheme of FIG. **8A**, the devices depicted in FIGS. **5G-5L** are labeled with the portable data terminal reference number **101** as well as the reference number indicating a host processor **1210**. In executing image capture module **1402** with use of portable data terminal **101**, it may be desirable, for purposes of enhancing an image quality of captured images, or a consistency of image quality between successively captured images to place portable data terminal **101** in a dark room at the time portable data terminal receives a trigger signal to commence image capture. Portable data terminal **101** may also be placed in a dark room fixture during image capture. A fixture such as the aforementioned dark room fixture may space portable data terminal a fixed distance from a substrate, *s*, to further enhance image quality and consistency.

Referring to FIG. **5F** another embodiment of the invention is described. In the embodiment of FIG. **5F** all of processing modules **1402**, **1404**, **1406**, **1408**, **1410**, **1422** and **1424** are incorporated into hand held verification device **100** such that housing **1100** having a generally domed configuration for shielding ambient light encapsulates all of modules **1402**, **1404**, **1406**, **1408**, **1410**, **1422** and **1424**. In the embodiment of FIG. **5F**, verification device **100** includes a display **194**. Referring to assembly views of FIGS. **6A-6D**, it is seen that, depending on the size of the display selected it may be necessary to enlarge housing **1100** so that display **194** may be installed in the location indicated without obstructing the path of image forming light rays. Configuring verification device **100** to include display **194** equips device **100** so that device **100** can execute user-interactive waveform analysis module **1424**. As explained previously, by execution of user-interactive waveform analysis module **1424** various information respecting bar codes is displayed on a display in response to user input commands. Such user-input commands may include commands to change the format of display and/or information displayed on display. In one

mode, device 100 during the execution of module 1424 may display on display 194 a scan reflectance profile 1670 as depicted in FIG. 5H. In another mode of operation as depicted in FIG. 5G, device 100 during execution of module 1424 may display on display 194 various measurement data, such as symbol contrast data 1671, edge contrast data 1672 and modulation data 1673. Device 100 may also display on display 194 decoded output data 1674 as depicted in FIGS. 5G through 5J. In that the hand held housing 1100 depicted in FIG. 5F includes a touch screen 195 associated with display 194, device 100 can be configured so that an operator switches between display formats by contact of a control button with a finger or a stylus. Device 100 can be configured so that the format of display can be switched from that depicted in FIG. 5G to that depicted by FIG. 5H by contacting control button 1066 with a finger or stylus. Because the screen formats of FIGS. 5G–5L may be displayed by host processor 1210 or by portable data terminal 101 configured in accordance with the integration module of FIG. 8A, or by verification device 100 configured in accordance with FIG. 8B, the devices depicted in FIGS. 5G–5L are labeled with the portable data terminal reference number 101 as well as the reference number indicating a host processor 1210, and in addition the reference number indicating verification device 100.

In accordance with the integration diagram of FIG. 8C, processing modules 1402 and 1412 are incorporated in device 100 within housing 1100 while processing modules 1406, 1408, 1410, 1422, 1424 and 1420 are incorporated in spaced apart host processor assembly 1210.

Referring again to features related to the structure of verification device 100 partial assembly views of device 100 are shown in FIGS. 6A–6D. As best seen in FIGS. 6A and 6B base 1114 of housing 1100 supports frame 1152 which extends upwardly from base 1100. At a bottom end of frame 1152 there is supported an electro optical assembly 1156 which carries imaging lens 1070 and image sensor 1060. Base 1114 and frame 1152 support imaging assembly 1140 so that imaging assembly 1140 including image sensor 1060 is positioned to a fixed optical path distance from bar code, B, when device 100 is positioned to perform bar code print quality measurements. At an upper end of frame 1152 there is supported a reflector 1075. Reflector 1075 is carried by reflector mount 1161 having pins 1162 extending therefrom. Pins 1162 in turn are received in pin receivers 1164 of support 1152 so that reflector 1075 is pivotally mounted on support 1152. Reflector 1075 folds imaging axis 1061 (FIG. 2A) so that image forming light rays reflected from a target, T, corresponding to a field of view are directed toward electro optical assembly 1156 incorporates lens 1070 and image sensor chip 1066 (FIG. 2A). A rear surface of frame 1152 supports a printed circuit board 1172 which carries several of the electrical components discussed with reference to FIG. 2A. Referring to further aspects of device 100, device 100 includes set screw 1174 which is positioned operationally relative to reflector 1150. Tightening and loosening set screw 1174 allows precise adjustment of the positioning of reflector 1075 so that the field of view of image sensor 1060 can be precisely adjusted. Device 100 should have at least one source of artificial illumination for use in illuminating bar codes subject to decoding and measuring. In the embodiment of FIGS. 6A through 6D, illumination is provided by LED printed circuit board 1180 which as seen in FIG. 6B includes a plurality of LEDs 1082. LED printed circuit board in the view of FIG. 6A is obscured from view by transparent dust cover 1186. Additional views

of components of device that are internal to housing 1100 are provided in the exploded assembly view of FIG. 6K.

Referring to the device 100 bottom view of FIG. 6C, alignment formations 1141, 1142, 1143 are as described earlier herein with respect to FIG. 1C. Alignment member 1150 including alignment formations 1141, 1142, 1143 in the embodiment of FIG. 6B is integrally formed with housing 1100. While alignment formations 1141, 1142, and 1143 in the embodiment of FIG. 1C and 6B have a discernable thickness and are structural elements, the alignment member 1150 of device 100 for aligning device 100 with bar codes can, include printed matter alignment formations. In FIGS. 6E–6I several alternative alignment members are shown. The alignment members 1150 of FIGS. 6E–6J all comprise transparent (e.g., glass, plastic) inserts having printed matter alignment formations thereon. The printed matter alignment formations may be comprised of e.g., ink, paint, dye, or stickers. Device 100 can be configured so that alignment members 1150 are replaceably received thereon, e.g., with modest strength adhesive. The embodiment of device 100 depicted in FIG. 1B includes a recess 1190 on which a replaceable alignment member, e.g., any one of members 1150-2 through 1150-7 may be received. Replaceable, transparent alignment members 1150-2, 1150-4, 1150-6, and 1150-7 include one or more center alignment formations 1192 which function in the manner of alignment formations 1142, for use horizontally centering of device 100 on a bar code. Replaceable alignment members 1150-2, 1150-4, 1150-5, 1150-6, and 1150-7 have laterally disposed alignment formations 1191 and 1193 which aid an operator in locating device vertically with respect to a vertical center of a bar code. Alignment members 1150-2, 1150-3, 1150-5, 1150-7 include alignment lines 1194. Alignment lines 1194 aid an operator in orienting device 100 so that a field of view of device 100 extends perpendicularly with respect to bars of bar code being subject to decoding and print quality measuring. It is seen that replaceable alignment members 1150-5 and 1150-7 include parallel sets of alignment lines 1194.

In accordance with its major aspects and broadly stated the present invention in one embodiment described is a bar code verification device having an ergonomic form factor characterized by a domed hand held trigger and a viewing window.

The verification device may be disposed in a network that includes a host processor system and other bar code reading devices which may include other bar code verification devices.

Processing circuitry for processing image signals corresponding to printed bar codes may be partially disposed within the hand held verification device and partially disposed within a host processor system spaced apart from and associated with the hand held verification device.

The hand held verification device may be in wireless communication with the host processor system to which it is associated.

The bar code verification system may include signal enhancement modules which interpolate constructed pixel values from actual pixel values and which correct for signal degradation resulting from high frequency spatial sampling.

These and other details and advantages are apparent from the detailed description of the preferred embodiment.

While the present invention has been particularly shown and described with reference to the preferred mode as illustrated in the drawings, it will be understood by one skilled in the art that various changes in detail may be effected therein without departing from the spirit and scope of the invention as defined by the claims.

The invention claimed is:

1. A device for verification of a bar code disposed on a substrate, said device comprising:

- (A) an imaging assembly including a solid state image sensor;
- (B) a hand held housing encapsulating a component of said imaging assembly, said hand held housing defining a front surface, a rear surface and side surfaces of said device, wherein walls of said hand held housing extend upward from said substrate when said device is positioned in a position to measure print quality of said bar code;
- (C) an illumination assembly at least partially disposed in said housing projecting an illumination pattern onto said substrate;
- (D) a window disposed at a front surface of said device, said window being light transmissive to enable an operator to view said bar code when said device is positioned in a position over said bar code;
- (E) a trigger disposed on said device, wherein said housing and said trigger are configured in a complementary manner so that an operator grasping said device in a grasping position can actuate said trigger with a digit of a hand that is grasping said device without releasing said device from said hand;
- (F) an image capture module incorporated in said device;
- (G) a bar code decoding module further incorporated in said device;
- (H) a bar code print quality measurement module incorporated in said device;
- (I) wherein said device is configured so that when said trigger is actuated, said device automatically executes said image capture module, said bar code decoding module and said bar code print quality measurement module, wherein said device when executing said image capture module captures a frame of image data corresponding to said bar code symbol, wherein said device when executing said bar code decoding module processes a frame of image data to determine a decoded out message, and wherein said device when executing said print quality measurement module determines at least one of a print contrast measurement, an edge contrast measurement and a modulation measurement of said bar code symbol.

2. The device of claim 1, wherein said device is configured so that when said device executes said image capture module, said device automatically compensates captured image data for fixed pattern noise attributable to illumination pattern nonuniformities.

3. The device of claim 1, wherein said device further includes:

at least one of an interpolation module and a high spatial frequency correction module incorporated in said housing, said interpolation module when executed by said device processing image data input to said interpolation module by determining constructed pixel values corresponding to interpolated pixel positions according to a nonlinear function, said high spatial frequency correction module when executed by said reader enhancing a frequency component of image data input to said high special frequency correction module.

4. The device of claim 1, wherein said device is configured to operate in a user-selectable calibration mode of operation, wherein said device when operating in said user-selectable calibration mode captures a test frame of image

data in such manner that said test frame represents nonuniformities of said projected illumination pattern projected by said illumination assembly.

5. The device of claim 1, wherein said side surfaces of said housing define contoured side grasping formations, said side grasping formations accommodating an operator's hand so that an operator stabilized said housing on a said substrate by grasping said side grasping formations.

6. The device of claim 1, wherein an upper portion of said housing includes a lip extending outwardly from a major body of said housing, said lip including a surface adapted to engage a digit of a hand of an operator that grasps said device when said operator lifts said device upwardly.

7. An optical reader comprising:

(A) an imaging assembly comprising a solid state image sensor having a plurality of photosensitive picture elements said imaging assembly further having an imaging lens focusing an image onto said solid state image sensor, said solid state image sensor being selected from the group consisting of a one dimensional image sensor and a two dimensional image sensor;

(B) an artificial light source;

(C) a hand held housing encapsulating at least one component of said imaging assembly, said hand held housing further encapsulating said artificial light source;

(D) a control circuit disposed within said hand held housing, said control circuit being in communication with said imaging assembly and said artificial light source, wherein said control circuit is configured to capture a frame of image data within a memory unit thereof, said frame of image data including a plurality of pixel values;

(E) at least one of an interpolation module and a high spatial frequency correction module incorporated in said housing, said interpolation module when executed by said reader processing image data input to said interpolation module by determining constructed pixel values corresponding to interpolated pixel positions according to a nonlinear function, said high spatial frequency correction module when executed by said reader enhancing a frequency component of image data input to said high special frequency correction module;

(F) a bar code decoding module incorporated in said housing;

(G) wherein said reader is configured so that said reader, in response to receipt of a trigger signal automatically captures a frame of image data and further automatically executes said at least one of said interpolation module and said high spatial frequency error correction module and further automatically executes said decoding module.

8. The optical reader of claim 7, wherein said optical reader further includes a bar code print quality measurement module executed by said control circuit.

9. The optical reader of claim 7, wherein said interpolation module when executed by said control circuit determines constructed pixel values corresponding to interpolated pixel positions according to a sinc function.

10. The optical reader of claim 7, wherein said interpolation module when executed by said control circuit determines constructed pixel values corresponding to interpolated pixel positions according to a sinc function modified by a windowing parameter.

11. The optical reader of claim 7, wherein said interpolation module when executed by said control circuit determines constructed pixel values corresponding to interpo-

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lated pixel positions according to a sinc function modified by an exponential windowing parameter.

12. The optical reader of claim 7, wherein said high spatial frequency correction module determines a Fourier transform of said image data input into said high spatial frequency correction module. 5

13. The optical reader of claim 7, wherein said hand held housing is adapted to shield ambient light from a bar code being subject to decoding, said hand held housing being of generally domed configuration and having a generally narrowing diameter from bottom to top. 10

14. The optical reader of claim 7, wherein said hand held housing is adapted to shield ambient light from a bar code being subject to decoding, said hand held housing being of generally domed configuration and having a generally narrowing diameter from bottom to top, said hand held housing further having an enlarged head portion including engagement surfaces adapted to engage at least one of a finger or a thumb of an operator when an operator lifts said hand held housing upwardly. 15 20

15. A bar code verification system for measuring the quality of a bar code symbol disposed on a substrate, said bar code verification system comprising:

(A) a bar code verification device having a housing, said bar code verification device further having an imaging assembly disposed in an interior of said housing, said bar code verification device having an image capture module and a bar code quality measurement module, wherein said bar code verification device develops bar code quality measurement data when executing said bar code quality measurement module, said bar code measurement data including at least one of symbol contrast measurement data, edge contrast measurement data, and modulation measurement data, wherein said bar code verification device further has incorporated in said housing at least one artificial light source illuminating said bar code symbol disposed on said substrate, said bar code verification device further having a radio frequency transceiver facilitating wireless data communication with a device spaced apart from said bar code verification device; 25 30 35 40

(B) a host processor assembly including a host display, said host processor assembly spaced apart from and in communication with said bar code verification device, said host processor assembly including a user-interactive waveform analysis module enabling an operator of said bar code verification system to view a graphical representation of image data corresponding to said bar code symbol, said user-interactive waveform analysis module further enabling an operator of said bar code verification system to view on said display data determined by said bar code print quality measurement module of said bar code verification device, wherein said host processor assembly and bar code verification device are configured so that said bar code verification device is freely moveable with respect to said host processor assembly, wherein said host processor assembly includes a radio frequency transceiver that is in wireless communication with said radio frequency transceiver of said bar code verification device; 45 50 55 60

(C) wherein said system is configured so that said bar code verification device in response to receipt of a trigger signal automatically executes said image capture module to capture image data representing said bar code symbol, and further automatically executes said bar code quality measurement module to develop bar code quality measurement data, wherein said bar code 65

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verification device, further in response to receipt of said trigger signal automatically and wirelessly transmits to said spaced apart host processor assembly, when communications capabilities there between are unimpeded, image data corresponding to said bar code symbol together with said bar code quality measurement data developed pursuant to execution of said bar code quality measurement module; and

(D) wherein said bar code verification device includes an impeded communication mode of operation in which said bar code verification device evaluates present data communications capabilities of said radio frequency transceiver of said bar code verification device, wherein said bar code verification device further in accordance with said impeded communications mode of operation, when determining that data communications are presently impeded, automatically archives image data and bar code print quality measurement data determined by said bar code verification device over the course of more than one decode and measurement session for later uploading to said host processor assembly.

16. The bar code verification system of claim 15 wherein said housing of said bar code verification device includes a base portion adapted to rest on said substrate, said base portion defining an opening, wherein said device further includes an alignment member disposed at said opening, said alignment member including a plurality of alignment formations that assist a user in aligning said bar code verification device with said bar code symbol disposed on a substrate.

17. The bar code verification system of claim 15, wherein said housing of said bar code verification device includes base portions and walls extending upwardly therefrom, said walls blocking ambient light rays which otherwise would reach said bar code.

18. The bar code verification system of claim 15, wherein said housing of said bar code verification device includes walls extending upwardly from said substrate when said device is positioned to perform bar code print quality measurement with respect to said bar code, said walls blocking ambient light rays which otherwise would reach said bar code, device further having a support structure disposed internal relative to said housing, said support structure supporting said imaging assembly at a fixed optical path distance relative to said substrate.

19. A portable data collection device for use in decoding and measuring a print quality of bar codes, said portable data collection device comprising:

(A) an imaging assembly including a solid state image sensor and an imaging lens focusing an image onto an active surface of said solid state image sensor, said solid state image sensor being selected from group consisting of a one dimensional image sensor having at least one row of photosensitive picture elements and a two dimensional image sensor having a plurality of rows and a plurality of columns of photosensitive picture elements;

(B) a portable, hand held housing encapsulating a component of said imaging assembly;

(C) a display disposed on a surface of said device;

(D) a keyboard disposed on a surface of said device;

(E) a graphical user interface incorporated into said device, said graphical user interface including a pointer that is displayed on said display, said device being configured so that a location of said pointer on said

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device is responsive to a user-input command to change a displayed location of said pointer;

(F) a trigger button disposed on said device;

(G) a radio frequency transceiver disposed within an interior of said housing facilitating data communications between said portable data collection device and a device spaced apart from said portable data collection device;

(H) an image capture module incorporated in said device;

(I) a bar code decoding module further incorporated in said device;

(J) a bar code print quality measurement module incorporated in said device;

(K) wherein said device is configured so that when said trigger is actuated, said device automatically executes said image capture module, said bar code decoding module and said bar code print quality measurement module, wherein said device when executing said image capture module captures a frame of image data corresponding to said bar code symbol, wherein said device when executing said bar code decoding module processes a frame of image data to determine a decoded out message, and wherein said device when executing said print quality measurement module determines at least one of a print contrast measurement, an edge contrast measurement and a modulation measurement of said bar code symbol; and

(L) a user-interactive waveform analysis module incorporated in said device, said user-interactive waveform analysis module enabling said verification device to display data on said display in a plurality of user-selectable display formats, said user-selectable display formats being selectable with use of said graphical user interface, wherein said device in a first of said plurality of user-selectable display formats displays at least a scan reflectance profile of said bar code symbol enabling an operator to discern information respecting a print quality of said bar code symbol by observation of said scan reflectance profile, and wherein said device in a second of said user selectable display formats displays at least one of said scan contrast data, edge contrast data, and said modulation data determined by said device during execution of said print quality measurement module.

20. The portable data collection device of claim 19, further comprising at least one of an interpolation module and a high spatial frequency correction module incorporated in said housing, said interpolation module when executed by said reader processing image data input to said interpolation module by determining constructed pixel values corresponding to interpolated pixel positions according to a nonlinear function, said high spatial frequency correction module when executed by said reader enhancing a frequency component of image data input to said high special frequency correction module.

21. The portable data collection device of claim 19, further comprising an interpolation module and a high spatial frequency correction module incorporated in said housing, said interpolation module when executed by said reader processing image data input to said interpolation module by determining constructed pixel values corresponding to interpolated pixel positions according to a nonlinear function.

22. The optical reader of claim 21, wherein said interpolation module when executed by said control circuit determines constructed pixel values corresponding to interpolated pixel positions according to a sinc function.

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23. The optical reader of claim 21, wherein said interpolation module when executed by said control circuit determines constructed pixel values corresponding to interpolated pixel positions according to a sinc function modified by a windowing parameter.

24. The optical reader of claim 21, wherein said interpolation module when executed by said control circuit determines constructed pixel values corresponding to interpolated pixel positions according to a sinc function modified by an exponential windowing parameter.

25. The portable data collection device of claim 19, further comprising a high spatial frequency correction module incorporated in said housing, said high spatial frequency correction module when executed by said reader enhancing a frequency component of image data input to said high special frequency correction module.

26. The optical reader of claim 25, wherein said high spatial frequency correction module determines a Fourier transform of said image data input into said high spatial frequency correction module.

27. A device for verification of a bar code disposed on a horizontal substrate, said device comprising:

(A) an imaging assembly including a solid state image sensor;

(B) a hand held housing encapsulating a component of said imaging assembly, said hand held housing having a plurality of surfaces that extend generally upward from said substrate when said device is positioned in a position to measure print quality of said bar code;

(C) an illumination assembly at least partially disposed in said housing projecting illumination onto said substrate;

(D) an aperture formed on said housing, said aperture being formed on said housing in such position that an operator can view said bar code through said aperture when said device is positioned in a position over said bar code; and

(E) at least one alignment formation for aiding alignment of said device relative to said bar code, said at least one alignment formation formed at a bottom of said device, said at least one alignment formation and said aperture being positioned so that an operator can view said at least one alignment formation through said aperture wherein said device is positioned on said horizontal substrate.

28. The device of claim 27, wherein said aperture receives a light transmissive window.

29. The device of claim 27, wherein said aperture receives a manually removable opaque window.

30. The device of claim 27, wherein said at least one alignment formation is formed on said housing.

31. The device of claim 27, wherein said at least one alignment formation is formed on a replaceable alignment member.

32. The device of claim 27, wherein said at least one alignment formation includes a center alignment formation for aiding horizontal centering of said device on said bar code.

33. The device of claim 27, wherein said at least one alignment formation includes a pair of laterally disposed alignment formations for aiding vertical centering of said device on a bar code.

34. The device of claim 27, wherein said at least one alignment formation is provided by an alignment light formed on a transparent member.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

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INVENTOR(S) : Charles E. Biss et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On Page 1, the Title is incorrect. Please delete the words "**DEVICE AND SYSTEM FOR VERIFYING QUALITY OF BAR CODES**" and replace with **--DEVICE AND SYSTEM FOR PROCESSING IMAGE DATA REPRESENTING BAR CODES--**

In the Specification:

Col. 16, Line 4. Please delete equation "Ex (k) := $8^{-\left(\frac{k}{a}\right)^2}$ " (eq. 1-6)"

and replace with --" Ex (k) := $e^{-\left(\frac{k}{a}\right)^2}$ (eq. 1-6)"--

In the Claims:

In Claim 1(G), Col. 27, Line 29. Please delete the words "said device;" and replace with -- said device; and--

In Claim 7(A), Col. 28, Line 17. Please delete the words "elements said" and replace with --elements, said--

In Claim 7(E), Col. 28, Line 43. Please delete the words "correction module;" and replace with --correction module; and--

In Claim 18, Col. 30, line 43. Please delete the words "code, device" and replace with --code, said device--

In Claim 19, Col. 30, line 54. Please delete the words "from group" and replace with --from a group--

Signed and Sealed this

Fourth Day of December, 2007



JON W. DUDAS

Director of the United States Patent and Trademark Office